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Managing Corn Rootworms with a Granular Semiochemical-Based Bait

A 1990 Multistate Evaluation

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G.R. Sutter, D.R. Lance, L.J. Meinke, J.E. Frana,
R.L. Metcalf, E. Levine, and J.M. Gaggero

Abstract

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This publication reports results of a project that tested the effects of a granular, semiochemical-based bait on adult corn rootworms—as opposed to the larvae—in Indiana, Illinois, Nebraska, and South Dakota. Western and northern corn rootworms are two corn rootworm species that have the greatest economic and environmental impact on maize production in the United States. Tests were performed on a field-scale basis and in geographically separate locations. The bait suppressed the corn rootworms using significantly less toxin per hectare than that typically used. While it was easy to handle and apply, the formulation did not readily adhere to plant structures and was easily blown or washed from the plant to the soil surface.

Keywords: corn, corn rootworm, cucurbitacin, *Diabrotica barberi*, *Diabrotica virgifera virgifera*, integrated pest management, semiochemical bait, *Zea mays*

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Contents

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Chapter 1

Introduction: The Problem and the Project

Gerald R. Sutter and J.M. Gaggero

Corn rootworms (Coleoptera: Chrysomelidae) are among the most economically and environmentally important insect pests in U.S. maize production. Metcalf (1986) estimated that crop losses and control costs attributed to corn rootworms approach $1 billion annually. The western corn rootworm (*Diabrotica virgifera virgifera* LeConte) and the northern corn rootworm (*D. barberi* Smith and Lawrence) are the two corn rootworm species that have the greatest impact on maize production in the United States. Larvae of these two species are oligophagous on roots of maize (*Zea mays* L.) and a few other grasses (reviewed by Branson and Krysan 1981). Extensive larval feeding can reduce yields of maize by limiting the plants' capacity for uptake of water and nutrients. Their impact on maize is obvious when roots are severely damaged and become susceptible to root lodging (Sutter et al. 1990). The plants then frequently tip over, which can interfere with mechanical harvesting.

At present, growers attempt to minimize larval feeding damage either by applying soil insecticides at planting or cultivation time or by rotating maize with nonhost crops. Western and northern corn rootworms lay eggs in August and early September, and the eggs overwinter in the soil before hatching the following growing season, usually in late May, with peak hatch in early June. Rotation of maize with nonhost crops generally controls the insects because suitable host material is unavailable to neonate larvae. However, the northern corn rootworm, and very rarely the western corn rootworm, can cause economic damage to maize planted in a consistent rotation with nonhost crops. This damage was originally attributed to egg laying in fields of nonhost crops during the year before maize was planted. However, recent evidence indicates that northern corn rootworm females tend to emigrate from maize fields in search of food, returning to these fields to lay their eggs.

A more conservative explanation for these infestations is that some northern corn rootworms populations show a high incidence of semivoltinism in the egg stage under appropriate conditions and thus flourish under strict alternate-year crop rotation schemes (for example, maize/soybean/maize) (see Krysan et al. 1986, Krysan 1993).

When growers plant maize on the same ground year after year, they typically rely on insecticides to protect their crop from larval feeding damage (see Sutter and Lance 1991 for a review of factors promoting continuous planting of maize). The most common insecticides used to manage corn rootworms is granular formulations of organophosphates, carbamates, or more recently, pyrethroids applied to the soil at planting time. These formulations are typically applied in a 15- to 20-cm-wide band directly over the row at a rate of about 1 kg of actual insecticide (AI)/ha (about 90 percent less AI for pyrethroids). Growers routinely apply these insecticides without assessing rootworm populations and the potential for damage in their fields or weighing the costs of materials and equipment against the benefits of possible control (Turpin and Maxwell 1976).

This prophylactic use has continued for a variety of reasons, including habit, aggressive promotion of chemicals by the agrichemical industry, and difficulties predicting the amount of economic damage caused by rootworms (Turpin and Maxwell 1976, Foster et al. 1986, Sutter and Lance 1991). Even when rootworm populations are sufficient to warrant control measures, the ability of soil insecticides to protect yield is highly variable, depending on such factors as rainfall patterns, soil characteristics (particularly soil moisture), maize variety, and rootworm population densities. Soil insecticides, providing they persist in lethal concentrations during the larval feeding period, are more consistent in reducing root lodging than in preventing yield loss in that they usually only protect the roots that are within the 15- to 20-cm treated zone at the base of the plant. However, even treated plants often lodge when there is extensive or heavy pressure from larval feeding. In addition, soil insecticides reduce numbers of beetles emerging from the soil by an average of only 40–50 percent, so they often do little to suppress populations from one year to the next.

Efforts to develop effective integrated pest management paradigms based on soil insecticides have met with limited success (Foster et al. 1986, Sutter and Lance 1991). The resulting reliance on prophylactic use of soil insecticides in the Corn Belt adds unnecessary costs to maize production, can be hazardous to growers during application, and has resulted in instances of groundwater and surface water contamination and poisonings of wildlife and livestock (US EPA 1985, McDonald 1987, Williams et al. 1988, National Research Council 1989).

An alternative strategy for managing corn rootworms with insecticides is to target the beetle or adult stage rather than the larvae. Compared with soil insecticides

(see Sutter et al. 1991), aerial applications of organophosphates or carbamates are typically much more effective at reducing numbers of rootworm beetles in maize fields (Pruess et al. 1974, Mayo 1976). Aerial applications of these formulations typically employ up to 1 kg AI/ha. This technology, in conjunction with scouting of fields to determine beetle densities and identify fields that exceed thresholds, is currently being used or recommended by a growing number of professional crop consultants in Nebraska and several other Corn Belt states. Due to the high motility of the beetles, applications of insecticides for suppression of adults appear to be most effective when a relatively broad area—several square kilometers—is managed (see Pruess et al. 1974). One major drawback to aerial application of broad-spectrum insecticides at these rates is their adverse effect on naturally occurring predators and parasites that normally prevent the buildup of secondary pests (Mayo 1976).

Alternatives to Conventional Management

Recent advances in our knowledge of the chemical ecology of corn rootworm beetles have provided potential alternatives to conventional management tactics. Cucurbitacins, which are extremely bitter tetracyclic triterpenoids found in many *Cucurbita* spp. (cucurbits) and certain other plants, are potent feeding stimulants for adult diabroticites (Metcalf et al. 1980). Cucurbitacins are probably not volatile enough to act as long-range attractants (Branson and Guss 1983), but a relatively large number of nonpheromonal attractants which have that potential have been identified in the past decade. These attractants include floral volatiles, especially from cucurbits (see Ladd et al. 1983, Andersen and Metcalf 1986, Metcalf and Lampman 1989 a and b), as well as some extremely effective blends and analogs of these volatiles (Lampman and Metcalf 1987). In addition, a single-component sex pheromone has been isolated from western corn rootworm females and has been shown to attract northern corn rootworm males (Guss et al. 1984, 1985).

Theoretically, attractants could lure beetles to bait particles, and cucurbitacins could then induce beetles to feed specifically on an insecticide. Results of laboratory bioassays and small-scale field studies clearly demonstrate that the efficacy of bait particles containing small amounts of insecticide (typically less than 1 percent) was greatly enhanced when minute amounts of cucurbitacins were added (Metcalf et al. 1987, Lance and Sutter 1991, Weissling and Meinke 1991a). For example, when starch particles containing 0.5 percent carbaryl plus cucurbitacins were sprinkled over maize plants in field cages, more than 90 percent of the beetles in the cages were killed in 48 hr. Similar formulations without cucurbitacins did not produce measurable mortality (Lance and Sutter 1991).

Certainly, the value of nonpheromonal attractants in baits is not as clear. Under optimal conditions, the more effective nonpheromonal attractants increased the capture of beetles in traps by 100 times or more (Metcalf and Lampman 1989b, Lance 1990). Similarly, attractants produce substantial increases in the numbers of beetles killed by toxic baits when the bait particles are placed in traps, in dishes, or on individual, widely spaced maize plants (Metcalf et al. 1987, Weissling and Meinke 1991 a and b). Nonpheromonal attractants did not influence the efficacy of baits broadcast over maize plants in field-cage tests (Lance and Sutter 1990, 1991). When point sources of attractants are closely spaced over a broad area, the effect of the attractant on the arrival of corn rootworm beetles at the individual points becomes negligible (Lance 1993). Nonpheromonal attractants can lure beetles from untreated portions of fields into areas that were selectively treated with bait. Up to now, however, attractants have been shown to produce, at best, only moderate increases in numbers of corn rootworm beetles within small plots (60–324 m^2) in maize fields.

Due to the motility of corn rootworm beetles, mortality produced by semiochemical-based baits in small plots cannot be extrapolated to predict efficacy in commercial fields or larger management areas. In one trial, beetle densities in maize plots 1–3 ha in size treated with baits initially decreased but rebounded due to immigration from surrounding untreated fields (Lance and Sutter 1992).

This publication reports the results of a series of trials conducted to evaluate a granular formulation of semiochemical-based bait in production maize fields in Indiana, Illinois, Nebraska, and South Dakota. Major objectives of the project were to evaluate the efficacy of a newly developed semiochemical-based granular bait formulation for suppression of adult corn rootworm populations on a field-scale basis and in geographically separated locations throughout the Corn Belt. Other considerations were to measure the effects of the bait application rate, determine environmental parameters that affect the efficacy of this management approach, and assess the impact of this technology on nontarget organisms.

Materials and Methods

Bait Formulation

Semiochemical and toxic components were formulated into a corn grit carrier by MicroFlo Inc., Lakeland, Florida, under the guidance of BioControl, Ltd. The bait contained 5 percent dried, powdered root of the buffalo gourd plant (*Cucurbita foetidissima* H.B.K.), which was the source of cucurbitacins, a small amount of insecticide (0.3 percent carbaryl), and 7 volatile, nonpheromonal attractants (each about 0.1 percent by weight). These volatiles included three attractants for northern corn rootworms (3-phenyl propanol, cinnamyl alcohol, and 4-methoxy phenethanol) and four attractants for western corn rootworms (4-methoxy cinnamaldehyde, 1,2,4-trimethoxy benzene, indole, and *trans*-cinnamaldehyde). The granular bait was passed through 1.41 × 1.41 mm mesh screen (14-mesh sieve) in the final formulation process.

Bait Application

A Cessna Ag Husky aircraft, equipped with a granular applicator calibrated to deliver a 15-m-wide swath of bait granules at a rate of 10–11.2 kg/ha, was used for all bait applications in Indiana, Illinois, Nebraska, and South Dakota. Particles were evenly distributed within the swath (D.R. Lance, personal observations, 1990).

Descriptions of plots, sampling methodologies to monitor life stages of corn rootworms, and other data acquired during this project are described in the following chapters by individual cooperators. The chapters are presented in the order in which the bait was applied.

Chapter 2

Nebraska

Lance J. Meinke

Materials and Methods

Two sites in Saunders County were used for this pilot study. At each site, two fields where maize had been grown in successive years and that were close to each other were randomly assigned as either a treated or an untreated field. At site 1, near Malmo (the Malmo site), the treated field consisted of 15.9 ha and the untreated field of 12.7 ha. The two fields were planted May 3, 1990 [day of year (DOY) 123], with the maize cultivar 'Pioneer 3180'. Both fields had center-pivot irrigation. At site 2, near Mead, on the University of Nebraska Agricultural Research and Development Center (the Station site), the 6.6-ha treated field and the 5.5-ha untreated field were planted DOY 127, May 7, with 'NC^+ 5990'. Neither field had irrigation.

Between 6:30 and 8:30 a.m on DOY 219 (August 7), 11.2 kg of semiochemical-based bait were applied per ha to one of two fields at each of the geographically isolated sites. Maize plants in all fields were in the blister stage of development (R–2) (Ritchie et al. 1992). A heavy dew was present on the plants at the time of application. Wind was less than 3.2 kmh from the south, relative humidity was 95 percent, and air temperature ranged from 16.5 to 17.0 °C.

Temperatures were mild at the Station site from DOY 219 to 235, August 7 to 23, ranging from a mean high of 28.1 °C to a mean low of 17.1 °C. During the 6-day period after bait application, air temperatures ranged from a mean high of 26.9 °C to a low of 14.9 °C. From DOY 236 to 257, August 24 to September 14, daily high temperatures were more seasonal, with a mean high of 34.0 °C and a mean low of 17.7 °C. Rainfall occurred four times at the Station site and three times at the Malmo site. Each field was irrigated one time.

Sampling

Each field was divided into 12 plots. An emergence cage that covered a single plant (Hein et al. 1985) was placed in each plot before bait application to record beetle emergence during the study period. At the Station site, the cage was placed on DOY 215, August 3, and at the Malmo site, it was set out on DOY 212, July 31. All beetles emerging from the soil within the area of the cage were collected every 3–8 days until emergence was completed (fig. 1).

Unbaited yellow sticky traps (Pherocon™ AM No-Bait traps, made by the Trece Corporation, Salinas, California), were used to estimate corn rootworm populations in treated and untreated fields during the study (Hein and Tollefson 1984). One trap was attached to a maize plant at ear height in each plot, near each emergence cage. Traps were initially placed in fields during late July. They were removed just before bait application and replaced immediately after application. Traps were checked at intervals ranging from 2 to 8 days. All western and northern corn rootworms were recorded per trap, and sex ratios were estimated from a subsample of each species (up to 25 beetles per species per trap).

Numbers of beetles on whole maize plants were counted 24 hr before and 24 hr after application and then periodically through DOY 233, August 21 (Hein and Tollefson 1984). Twenty-seven sampling sites per field were distributed in a U-shaped pattern covering all 12 plots of each field; 2 plants were randomly selected at each site from which beetle counts were made.

In each plot, a 2-m^2 area kept weed-free during the study was used for counting dead western and northern corn rootworms found on plants and the soil surface. The mortality rate (fig. 2) and the sex of dead beetles were recorded daily for 5 consecutive days after bait application.

Bait granules were collected from plants at the Malmo site on the 2nd and 6th days after application and bioassayed in the laboratory to measure adulticidal activity of the formulation after exposure to the environment. Field-collected granules were placed in the bottom half of glass Petri dishes that were fitted with cylindrical plastic containers. The top of each container was enclosed with a plastic lid that had a circular vent covered with nylon mesh. A water-moistened cotton wick placed in each container provided moisture to beetles for the duration of the bioassay.

Bioassays were no-choice tests, as no food source other than the bait granules was provided. Ten unsexed, field-collected western corn rootworms were introduced into each container. Containers were then arranged in a completely random design. Four replications were performed 2 days postapplication, and 7 replications were performed 6 days postapplication and held at 25 $\pm$ 1 °C, with a photoperiod of 14:10 (L:D). An equal number of containers without bait were included as controls. Western corn rootworm mortality was recorded after 24 hr and ranked and analyzed by the Kruskal-Wallis test (χ^2 approximation) (Steel and Torrie 1980).

At the end of the growing season after fields were harvested, the frame method (Hein et al. 1985) was used to collect soil samples and estimate corn rootworm egg densities. Each field was divided into 20 plots and 1 sample was excavated per plot. A sample consisted of a 10.2-cm-wide × 76-cm-long × 20-cm-deep volume of soil dug perpendicularly to the direction of existing maize rows. The excavated soil was mixed thoroughly and three 0.47-L subsamples were collected per trench, frozen, and later processed to recover *Diabrotica* eggs (Shaw et al. 1976). Eggs per volume of soil were transformed (log [x + 0.1]) and then analyzed by analysis of variance (SAS Institute 1985) to examine the effect of treatment and location on egg densities.

In 1991, fields at the Station site were again planted in maize. No soil insecticide was applied at planting time. During August, 30 plants were dug per field (5 plants from 6 sites per field), and corn rootworm larval feeding damage was assessed using the 1–6 root rating scale (Hills and Peters 1971). No evaluations of root damage were made at the Malmo site.

Results and Discussion

The bait greatly reduced western corn rootworm population densities within 24 hr of application (fig. 3.: at the Malmo site an 83.8 percent mean reduction per plant, and at the Station site a 57.8 percent mean reduction). However, Malmo and Station populations were only reduced to levels below one published economic threshold (0.5 beetles per plant after initial application [Wright et al. 1992]) on the 1st and 3rd of the five postapplication sampling dates, respectively.

The mean number of beetles caught on yellow sticky traps also dramatically decreased during the 48-hr period after bait applications. The Malmo site showed an 89.3 percent reduction and the Station site, a 70.2 percent reduction (fig. 4). At Malmo, western corn rootworm populations were held below a published economic threshold of 6 beetles per trap per day (Hein and Tollefson 1985) for 10 days postapplication before exceeding the threshold. At the Station site, despite the population reduction, postapplication western corn rootworm population levels remained above the economic threshold from the application date until DOY 241, August 29.

Adult western corn rootworms emerged from Malmo and Station plots until DOY 241, or August 29, 1990 (fig. 1). However, peak emergence appeared to be earlier at the Malmo site than at the Station site. The mean number of western corn rootworms collected per emergence cage per day increased at the Station site (especially the untreated plot) during and just after bait application (fig. 1). This may partially explain the corresponding increase in western corn rootworms caught per sticky trap per day during this same period (fig. 4). The difference in emergence profiles between sites may have contributed to the apparent differences in western corn rootworm control among sites noted previously (figs. 3 and 4).

Both male and female western corn rootworms were killed by the semiochemical-based bait (table 1). Dead western corn rootworms were found in treated fields for 5 days after application (fig. 2). Dead western corn rootworms were only found at the untreated Station site on one date, DOY 220, or August 8.

Laboratory bioassays indicated that significantly higher mortality of western corn rootworms occurred from granule than nongranule treatments 2 days and 6 days postapplication. However, efficacy of the bait greatly declined by 6 days after application. Two days postapplication, the mortality with bait was 77.5 percent ± 6.3 percent and without bait, 2.5 percent ± 2.5 percent. Six days postapplication, mortality with bait was 27.1 percent ± 3.6 percent and without bait, 0.0 percent ± 0.0 percent. These results suggest that under the conditions of the study, bioactivity of the formulation was substantially reduced after 5 days in the field.

Northern corn rootworm populations were relatively low in comparison to western corn rootworm populations (figs. 3 and 5). After pollination, the mean number of northern corn rootworms per plant never exceeded 0.52 at the Malmo site or 0.96 per plant at the Station site (fig. 5). An unexplained increase in northern corn rootworms per plant was recorded in both treated and untreated fields 1 day after bait application. However, a dramatic drop in the number per plant was recorded in treated fields 3 days after bait application (fig. 5). This suggests that factors other than the bait application (for example, beetle movement or environmental conditions) may have affected the populations on DOY 220, August 8, and that northern corn rootworms may not have responded as quickly to the bait formulation as the western corn rootworms did.

More eggs were found in untreated fields than in treated fields. In untreated soil, the mean number per 0.47 L of soil was 4.05 ± 0.74 (*SEM*), and in treated soil, the mean was 3.20 ± 0.54, but the difference was not statistically significant. This trend was consistent at each site per 0.47 L of soil. At the Malmo site, untreated soil yielded a mean of 6.0 eggs ± 1.3 and treated soil a mean of 4.6 eggs ± 1.0. At the Station site, untreated soil yielded 2.1 eggs ± 0.5 and treated soil, 1.9 eggs ± 0.6. However, significantly more eggs

were recovered at the Malmo site than the Station site. The relative variation [(*SEM*/mean eggs in a field)(100)] in egg densities per field ranged from 21.9 to 32.3.

During 1991 at the Station site, we found the mean root damage rating in the 1990 untreated field to be numerically higher than the mean root damage rating in the 1990 treated field (untreated, 4.30 ± 0.39 *SEM*, treated, 3.27 ± 0.22 *SEM*). The difference in root ratings between treated and untreated fields is greater than that which would have been predicted based on estimates of egg populations in each field. The finding suggests that frame samples may not have been taken at the appropriate depth in dryland fields to recover a large percentage of the eggs present, especially since the Station site had numerically larger western corn rootworm populations than the Malmo site. Weiss et al. (1983) and Gray et al. (1992) have shown that a large percentage of western corn rootworm eggs can be found below 20 cm in dryland fields. The irrigation at the Malmo site during the egg-laying period also may have contributed to the differences in numbers of eggs recovered among sites. Weiss et al. (1983) have also shown that a high percentage of western corn rootworm eggs can be found in the top 10 cm of the soil profile under irrigated conditions.

Conclusions

The granular semiochemical-based bait formulation did kill male and female corn rootworm beetles in the field, resulting in dramatic postapplication reductions in beetle densities. Bait applications also reduced egg densities in treated plots, which showed less corn rootworm larval feeding damage when maize was planted the following season. In spite of this, the formulation did not reduce corn rootworm populations at the time of application to levels adequate for effective use in a management program.

To be a viable commercial product in maize production systems, improvements in the formulation are needed. Baits need to be placed on the plant canopy and need to adhere to the plant to remain effective. Past studies show the efficacy of semiochemical-insecticide granules is greatly reduced when granules fall to the ground (Weissling and Meinke 1991a) or are placed near the soil surface (Weissling and Meinke 1991b) . Formulations should also kill more beetles at the time of application and exhibit longer residual bioactivity in the field. A formulation with these characteristics would initially reduce corn rootworm populations to levels well below established thresholds and would provide more of a buffer against population resurgence (late emergence and immigrants). The availability of a better formulation would also enable important management questions about adult populations to be experimentally addressed, such as application timing, rates, and single field versus area-wide management approaches.

Table 1. Ratios of dead male:female corn rootworm beetles collected from treated plots at two sites in Nebraska

	Malmo site		Station site	
Day of year	Western corn rootworms	Northern corn rootworms	Western corn rootworms	Northern corn rootworms
220	2.2	6.0	1.1	1.5
221	0.3	all ♀	2.3	3.5
222	0.8	—	3.2	all ♂
223	0.5	1.0	1.0	—
224	all ♂	all ♀	3.0	all ♂

— = samples where no beetles were collected.

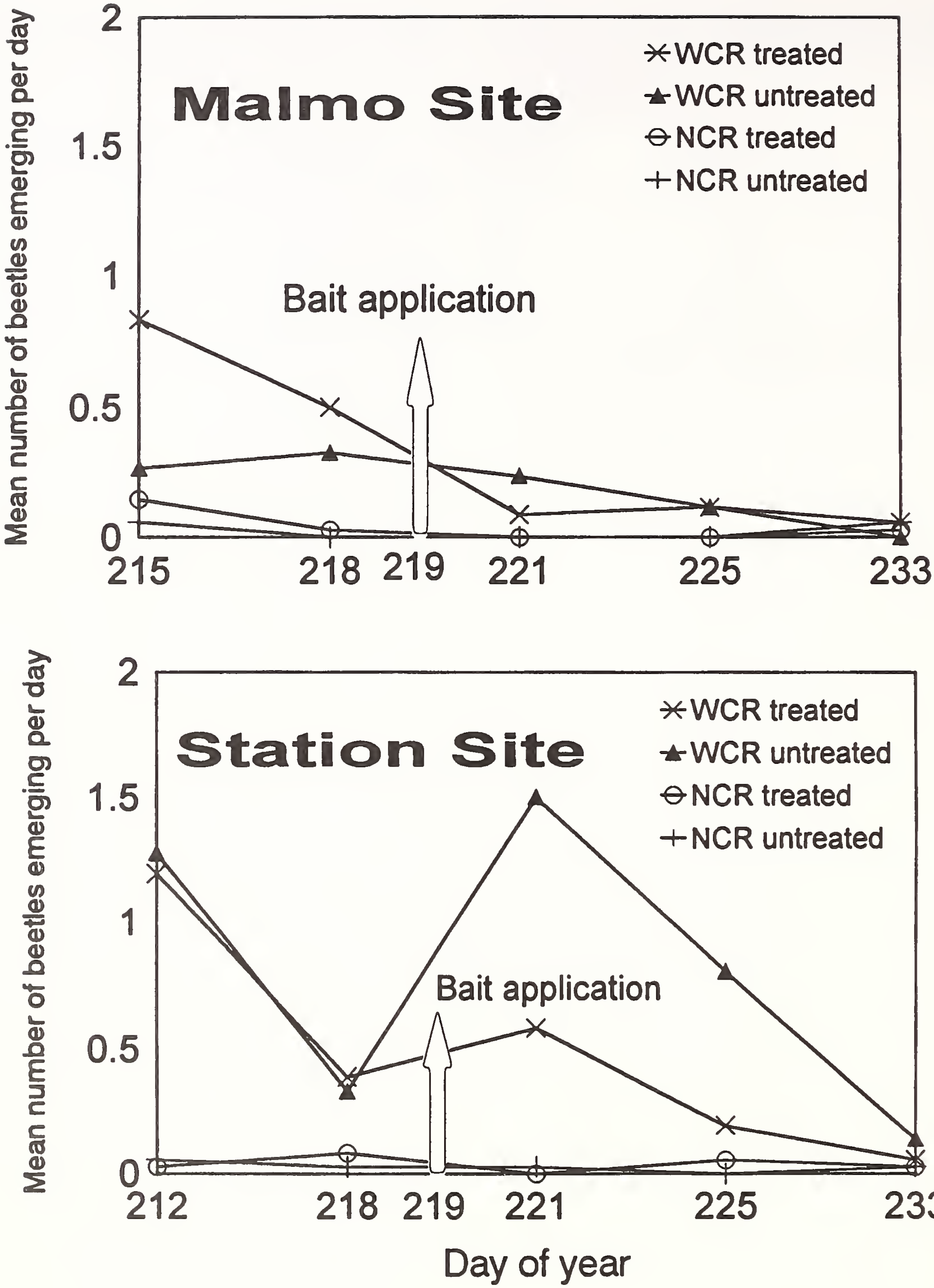

Figure 1. Mean number of corn rootworm beetles emerging from the soil per day from single plant emergence cages. Each data point is the mean for a collection period; for example, at the Station site, data points on DOY 212 represent 6-day means, DOY 212–218. WCR = western corn rootworms, NCR = northern corn rootworms.

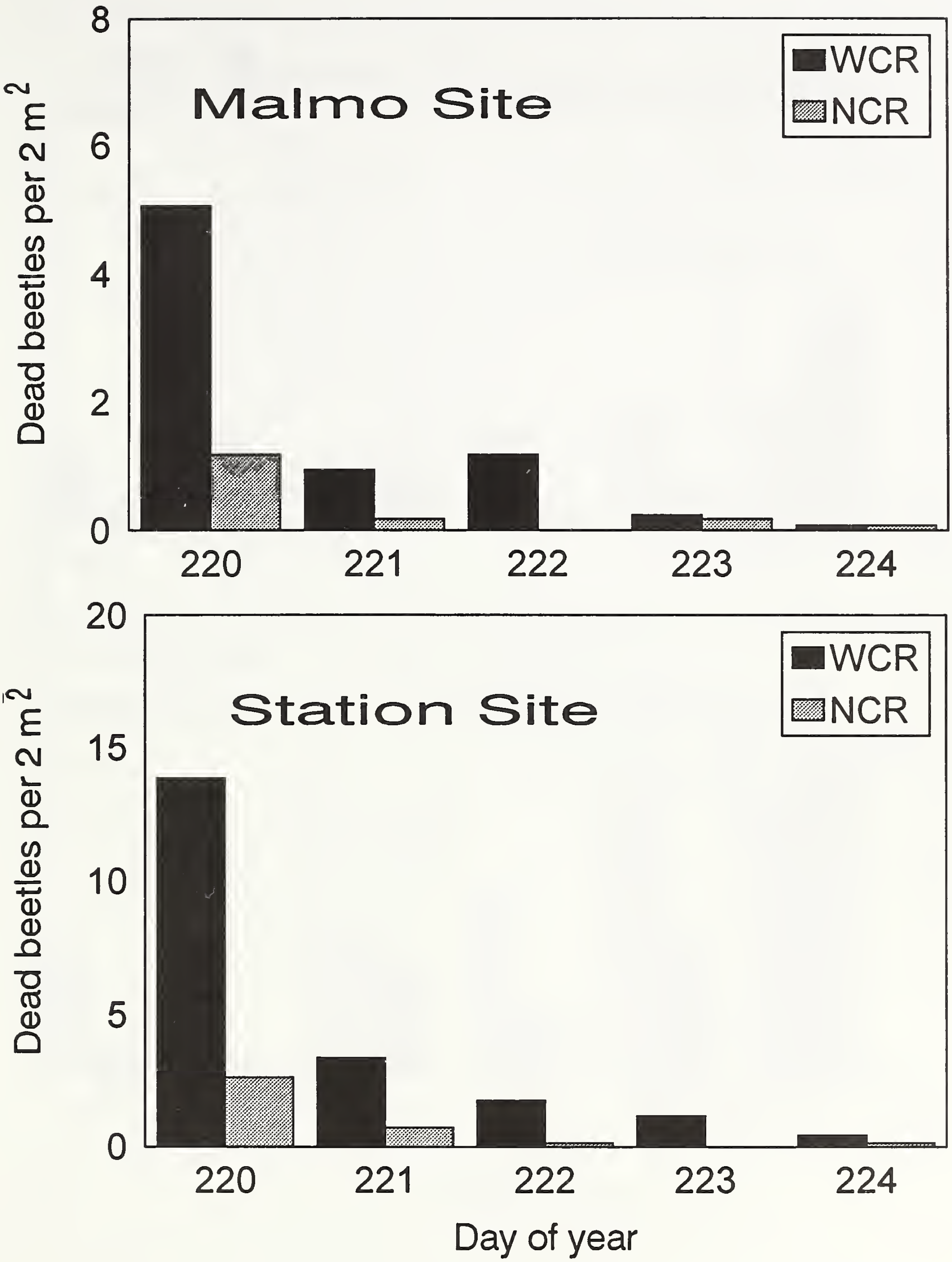

Figure 2. Mean number of dead corn rootworm beetles collected from plants and the soil surface per 2-m^2 area. WCR = western corn rootworms, NCR = northern corn rootworms. Bait was applied on DOY 219.

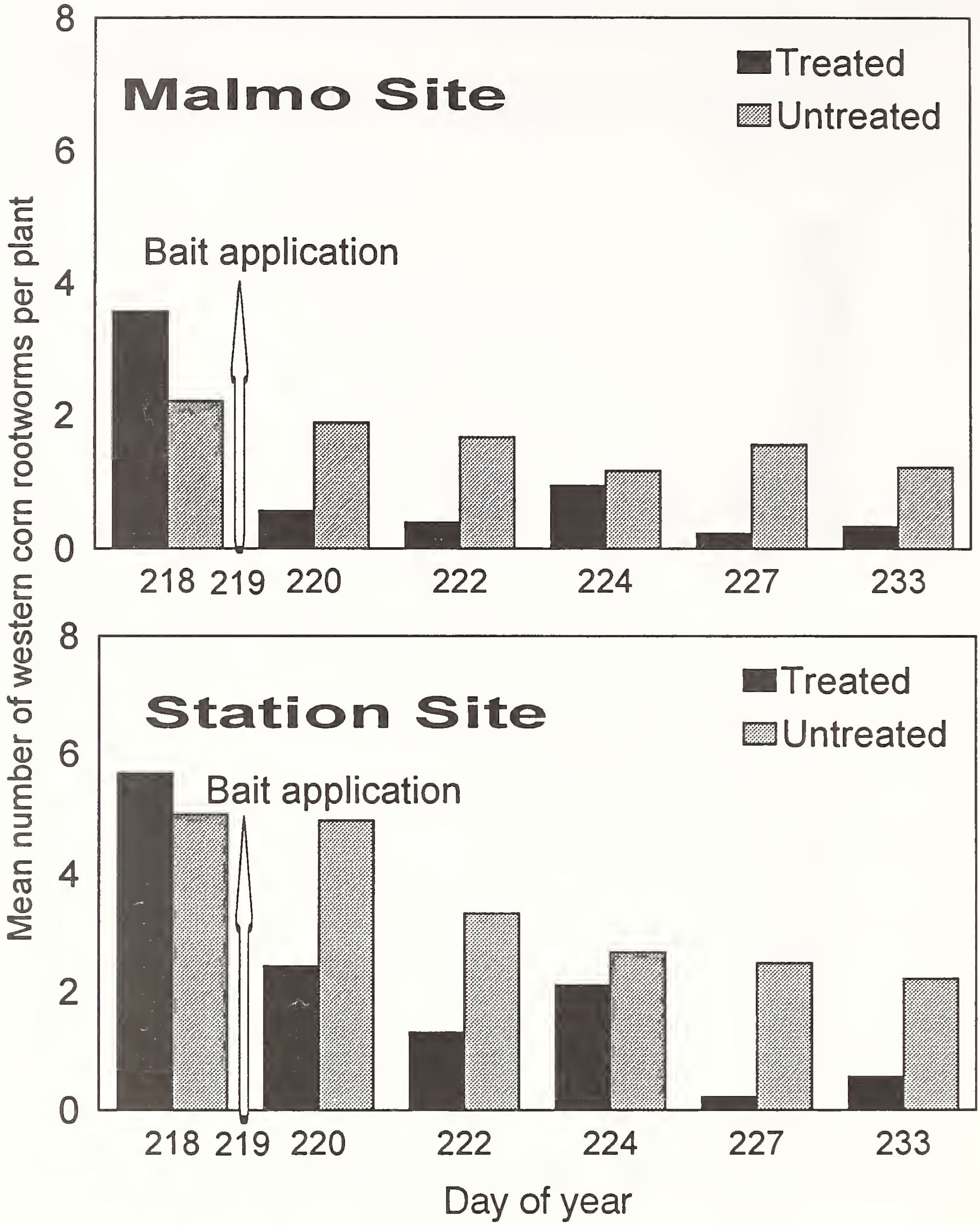

Figure 3. Mean number of western corn rootworm beetles per plant based on whole plant counts

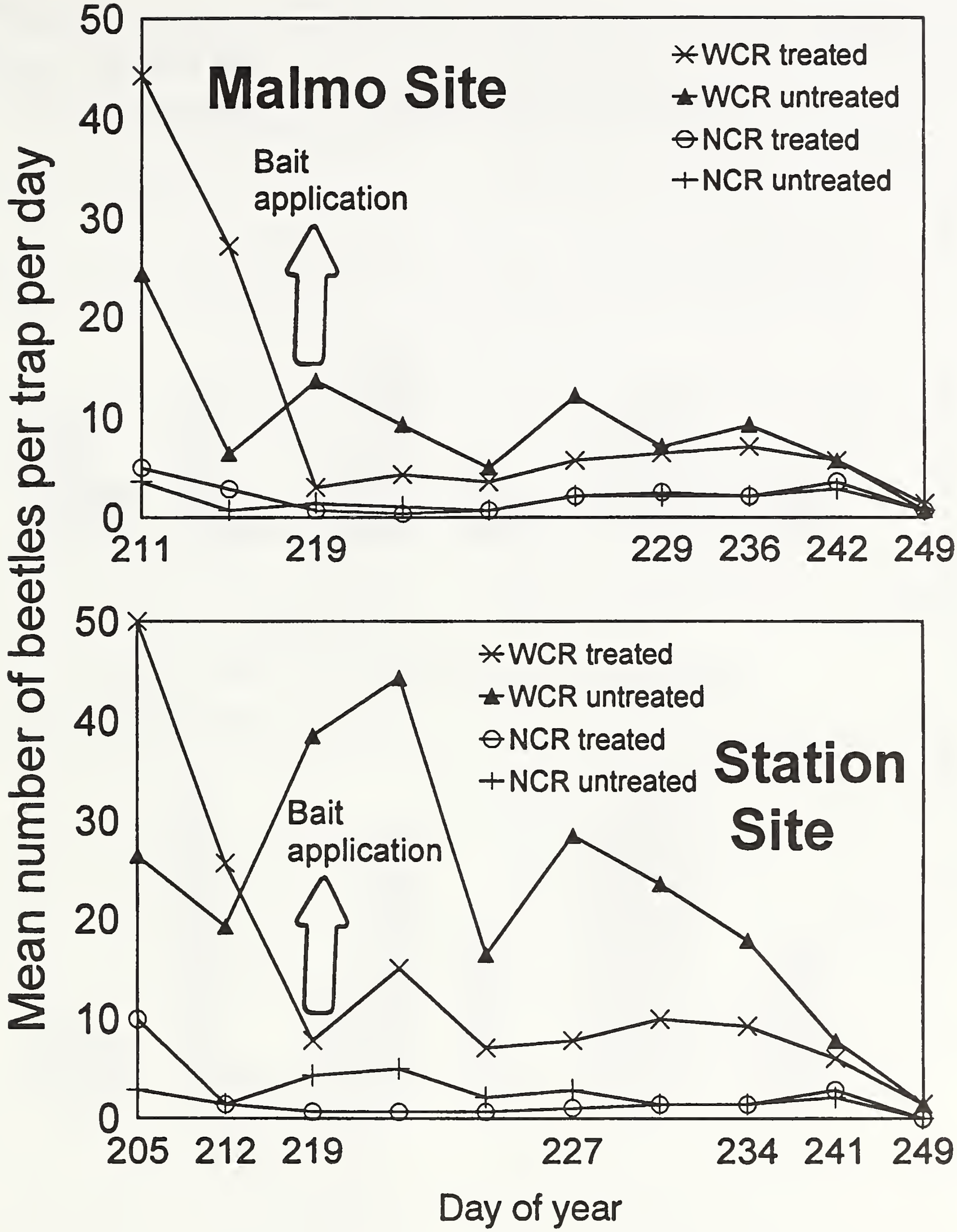

Figure 4. Mean number of corn rootworm beetles captured per unbaited yellow sticky trap per day. Each data point is the mean for a collection period; for example, at the Station site, data points on DOY 205 represent 7-day means, DOY 205–212. WCR = western corn rootworms, NCR = northern corn rootworms.

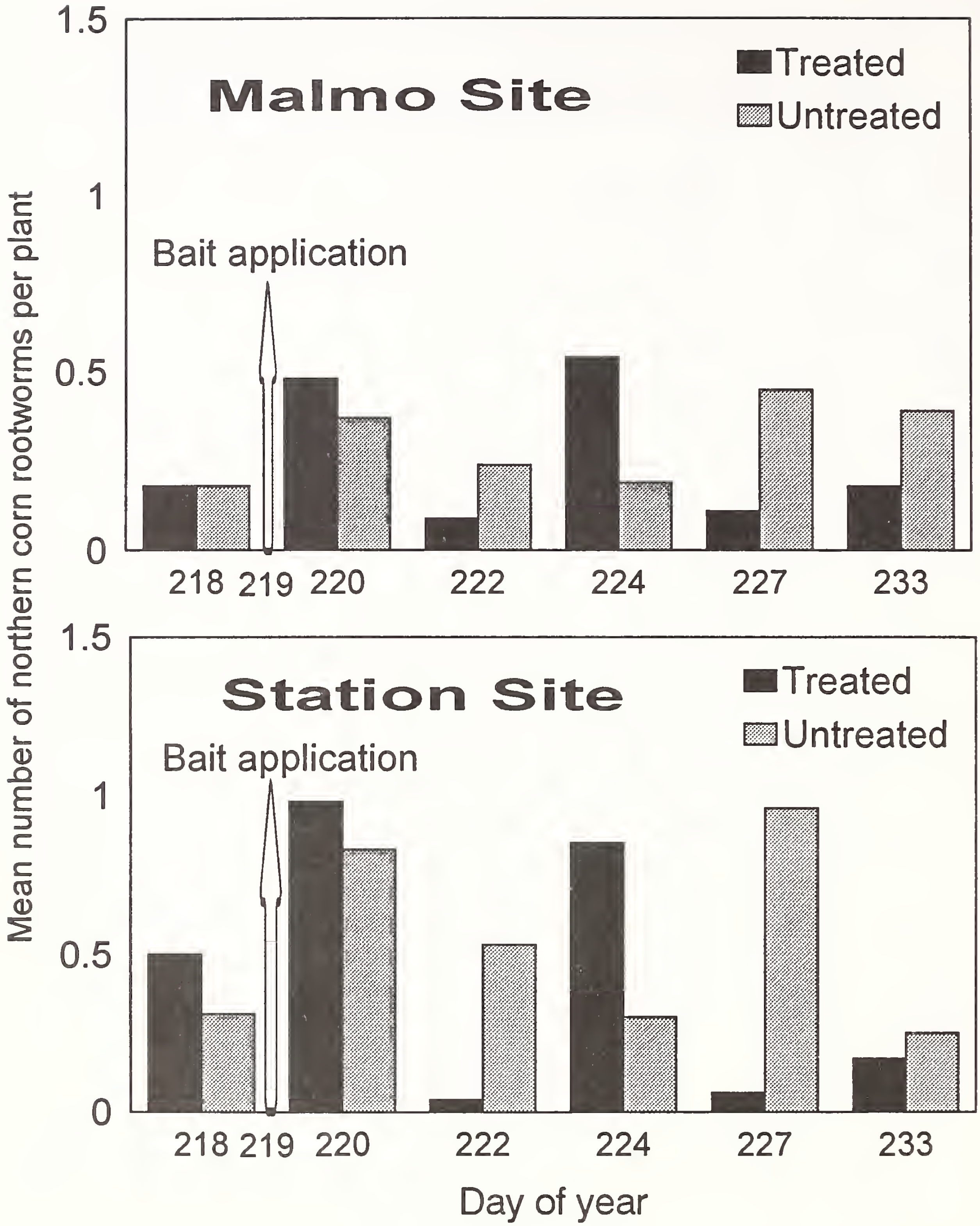

Figure 5. Mean number of northern corn rootworm beetles per plant based on whole plant counts

Chapter 3

Indiana

Jorge E. Frana, Larry W. Bledsoe, and F. Tom Turpin

Materials and Methods

Populations of corn rootworms in Indiana in 1990 comprised about 95 percent western corn rootworms, with the remaining 5 percent primarily northern corn rootworms. The southern corn rootworm, *D. undecimpunctata howardi* Barber, occurred rarely.

Weather conditions in 1990 were rather atypical in that the growing season followed a mild winter and a very cold spring. A delayed but warmer-than-normal summer had record rainfall, making it the wettest year since 1895.

Five production maize fields were selected to determine the efficacy of an application of semiochemical-based bait in suppression of corn rootworm populations. Field 1 was 64.8 ha (divided into a treated and an untreated plot of 32.4 ha each); field 2 was 40.5 ha (24.3 ha treated and 16.2 ha untreated); field 3 was 40.5 ha (24.3 ha treated and 16.2 ha untreated); field 4 was 32.4 ha (20.3 ha treated and 12.1 ha untreated); and field 5 was 26.3 ha (16.2 ha treated and 10.1 ha untreated). Field 3 was in White County, and all others were in Tippecanoe County.

Plots were treated at the rate of 11.2 kg granular bait/ha between 6:00 a.m. and 10:30 a.m. on DOY 220, August 8. The bait was applied evenly across all treated areas in 12- to 15-m swaths. At the time of application, the air temperature was 9˚C, the wind was calm, and a heavy dew was on the plant canopy. Approximately 3.7 cm of rain fell across the entire study area on the fifth day following application.

Ten unbaited yellow sticky Pherocon™ AM No-Bait traps were placed on randomly selected plants 3 days before treatment in each of the treated and untreated areas. Traps were replaced the day after application and then every 7 days or after a significant rain, whichever occurred first. Populations of corn rootworms were monitored by inspecting traps daily during the first 10 days after treatment. Beetles were removed from the traps, counted, and sexed when possible.

Populations of corn rootworms were also monitored by counting beetles on 2 entire maize plants at 27 locations within each plot. At that time, beetles were also collected and placed in vials containing 75 percent alcohol to determine the stage of ovarian development using the following 5-point scale (and illustrations) described by Cinereski and Chiang (1968): 1 = only a few developed eggs; 2 = more eggs developing and eggs larger relative to those in stage 1; 3 = more developed eggs than stage 2 and ovary not fully expanded; 4 = ovary fully expanded with developed eggs and considered the beginning of oviposition; and 5 = spent ovary.

Dead beetles within a 2 × 0.75 m area on the soil surface were counted 24 hr after treatment in 10 arbitrarily selected locations within each plot. All beetles were sexed.

In 1991, four 38 × 76 cm emergence traps were placed in plots 2 and 3, which were treated in 1990. Ten unbaited yellow sticky traps were randomly distributed in untreated plots and in each of the areas that had been treated in 1990. All remaining plots treated with bait in 1990 were planted in soybeans in 1991.

Data were subjected to analysis of variance, regression analysis, and assignment of confidence limits (SAS Institute 1989).

Results and Discussion

The total number of western corn rootworm beetles caught on sticky traps before and after treatment are shown in figure 1; numbers are combined for the five fields. Predicted means for treated and untreated were fitted to a third-degree polynomial equation. The average number of western corn rootworm beetles in treated and untreated plots from the five fields were different on DOY 219, before bait application. Counts of beetles on yellow sticky traps in treated plots indicated high mortality, compared with the number captured in control plots for the 5 consecutive days following application. However, several days after application, beetle numbers increased steadily in the treated plots and decreased in the untreated plots. By 8 days after application, populations were similar and remained so for the rest of the trapping period.

The average ovarian developmental stage (table 1) indicated that treatment was timely for preventing egg laying, the average being less than stage 4. However, at any time after bait application, beetles could be found with ovaries rating a stage 4, a situation that allowed some laying. The fact that beetle populations rebounded in treated plots following rain (which occurred 5 days after application) and gravid females were present in fields after bait application suggests that determining ovarian development was only a partial success in controlling adults under these field conditions.

Western corn rootworm densities per plant also suggested that populations in the treated plots initially decreased. However, 9 days after treatment, beetle numbers increased to levels similar to those observed in the control plots (fig. 1).

The proportion of beetles per yellow sticky trap was always skewed toward the males (fig. 2). This result may have several reasons. First, more males than females may have been present in midsummer due to the earlier emergence of male beetles. Second, more crepuscular movement of males was observed throughout the plant canopy, possibly associated with feeding and reproductive behavior. This movement would have increased the likelihood of male beetles encountering a trap.

Averaged over the 5 treated plots, we recorded 9.1 dead male and 2.4 dead female western corn rootworm beetles in 2×0.75 m quadrants on the soil surface 24 hr after bait application. Because no beetles were found dead in the untreated plots, the mortality observed in treated areas was attributed to the bait application. It is also important to note that beneficial ladybird beetle (Coccinellidae) larvae and adults were found dead on the ground in the treated plots only.

Conclusions

Application of this granular bait as an adulticide for management of western corn rootworm populations showed a rapid reduction of beetles in the treated plots, compared with the untreated plots. The residual activity of the bait was brief, lasting only until the first significant rain. Application of the bait formulation was acceptable since granules adhered to the corn leaves for several days. However, the period of bioactivity was not long enough to prevent egg laying by immigrating females.

Table 1. Ovarian developmental stage of female corn rootworm beetles collected in treated and untreated plots in five fields in Indiana

	Ovarian developmental rating*									
	Field 1		Field 2		Field 3		Field 4		Field 5	
Day of year	T†	U‡	T	U	T	U	T	U	T	U
219	2.2	2.2	2.1	2.3	2.4	2.6	1.5	3.1	2.4	2.4
220	2.1	2.0	1.9	2.4	3.0	2.8	2.7	2.5	3.0	2.7
221	3.1	3.3	2.8	2.6	3.4	3.5	3.8	3.4	3.7	3.4
225	4.1	4.2	3.4	2.7	2.4	2.4	2.5	2.2	1.5	2.3
228	3.1	3.5	2.3	2.7	2.5	2.7	2.7	3.0	3.6	2.9
234	3.0	3.3	4.2	3.2	2.8	2.9	2.6	2.7	3.1	2.6
244	3.3	3.8	3.9	3.9	3.3	3.5	3.9	2.0	2.4	4.0

* The rating scale is as follows: 1 = only a few developed eggs; 2 = more eggs developing and eggs larger relative to those in stage 1; 3 = more developed eggs than stage 2 and ovary not fully expanded; 4 = ovary fully expanded with developed eggs and considered the beginning of oviposition; and 5 = spent ovary (Cinereski and Chiang 1968).

† T = treated.

‡ U = untreated.

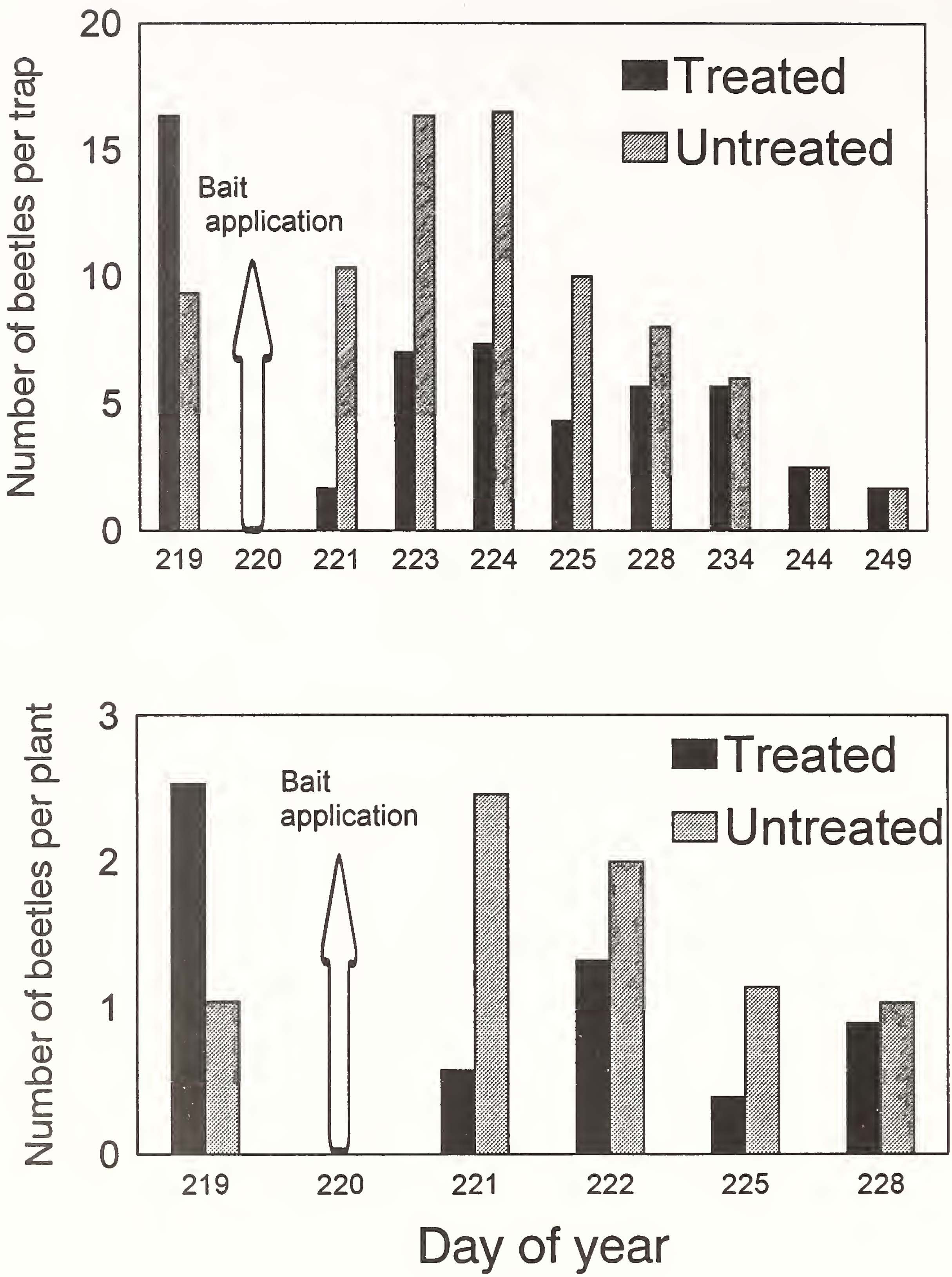

Figure 1. Western corn rootworm beetles captured per plant and per unbaited yellow sticky trap in untreated and treated plots

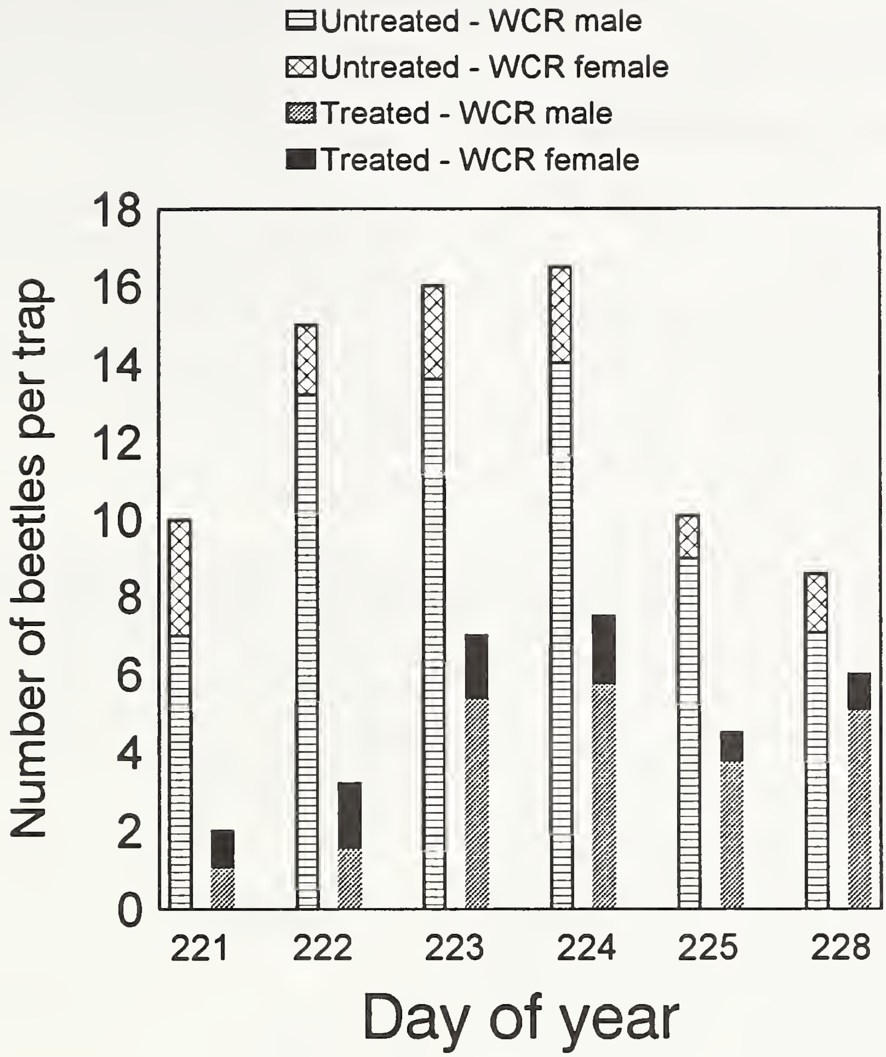

Figure 2. Number of male and female western corn rootworm beetles on unbaited yellow sticky traps in treated and untreated plots

Chapter 4

Illinois, Champaign County

Robert L. Metcalf, Lesley Deem-Dickson, and Richard L. Lampman

Materials and Methods

A 32-ha maize seed production field near Pesotum, in Champaign County, Illinois, was treated with the semiochemical-based bait on DOY 221, August 9, between 7:15 a.m. and 8:00 a.m. The plant canopy at that time was moist with morning dew and the plants were silking (R–4 stage). An adjacent 32-ha field was left untreated as a control. Examination of individual plants in both fields before bait application revealed an average of 0.64 corn rootworm beetles per plant (number of examined plants = 500). Immediately after application, the mean number of visible bait granules per leaf was 11.6 ± 1.4 (number of examined leaves = 37). The first significant rainfall after application occurred on DOY 224, August 12.

The effectiveness of the bait was measured by (1) counting the beetles on 100 maize plants at each of 4 corners of the treated and untreated control fields and (2) by placing at each of the 4 corners of the treated and untreated fields 4 replicates of unbaited, yellow sticky Solo Cup traps (Levine and Metcalf 1988) and 4 replicates of yellow Solo Cup sticky traps, each baited with 100 mg of an attractant consisting of equal portions of 1,2,4-trimethoxybenzene, indole, and cinnamaldehyde, called the "TIC" attractant. Yellow Solo Cup traps were used in lieu of the yellow sticky Pherocon™ AM No-Bait traps. While the two performed nearly equally in capturing beetles, the Solo Cup traps cost about 90 percent less.

Results and Discussion

The impact of the bait on corn rootworm populations was readily apparent by the number of beetles on each plant and by the number captured in traps in the treated and untreated areas. Within 15 minutes after bait application, dead and moribund beetles were observed on leaves and in leaf axils and whorls of plants, as well as on the soil surface. Mean counts of western and northern corn rootworms per plant at various intervals following bait application are presented in table 1. Based on these data, the bait suppressed corn rootworm populations over a 2-wk period. Similar results were found using yellow sticky Solo Cup traps with and without the TIC attractant (tables 2 and 3).

Effectiveness of the baits after 1, 2, 7, and 14 days is depicted in tables 2 and 3. Sticky trap catches greatly improved on average by the use of the TIC attractant. We believe there was considerable migration of rootworm beetles into the treated area from the adjacent control area.

There was no evidence of detrimental effects on populations of beneficial insects. It is evident from this study that the aerial application of toxic baits with attractants can produce dramatic decreases in adult corn rootworm populations at the time of egg laying and can adequately suppress adult populations, compared with conventional soil or aerial insecticide applications.

Conclusions

The granular bait was highly effective in reducing the number of western and northern corn rootworms in the treated plots. The bait appeared to be effective in continuing to kill beetles for at least 7 days. Increases in beetle numbers were most noticeable 14 days after bait application. The aerial application of the bait seemed to be an acceptable method for suppression of corn rootworm adults.

Table 1. Mean number of western and northern corn rootworms per maize plant in untreated and treated fields in Champaign County, Illinois

	Day of year			
Field	**221**	**222**	**228**	**235**
Western corn rootworms				
Untreated	0.70 (.05)*	0.72 (.18)	0.94 (.06)	0.89 (.06)
Treated	0.09 (.02)	0.10 (.04)	0.10 (.01)	0.33 (.07)
Northern corn rootworms				
Untreated	0.10 (.01)	0.14 (.11)	0.25 (.03)	0.28 (.04)
Treated	0.00 (.00)	0.00 (.00)	0.01 (.01)	0.04 (.01)

* *SEMs* in parentheses.

Table 2. Mean number of western and northern corn rootworm beetles on yellow Solo Cup traps (*N* = 16) baited with TIC in untreated and treated plots in Champaign County, Illinois

	Number of days following bait application			
Plot	**1**	**2**	**7**	**14**
Western corn rootworms				
Untreated	503.3 (40.1)*	256.0 (22.0)	249.0 (22.0)	457.0 (22.0)
Treated	32.6 (4.8)	96.0 (11.0)	81.0 (11.0)	237.0 (16.0)
Northern corn rootworms				
Untreated	17.0 (1.9)	36.0 (2.0)	72.0 (5.4)	72.0 (6.2)
Treated	0.1 (0.1)	0.4 (0.2)	9.5 (1.1)	31.6 (5.6)

Note: Traps were exposed for 24 hr.

* *SEMs* are in parentheses.

Table 3. Mean number of western and northern corn rootworm beetles on unbaited yellow Solo Cup traps (N = 16) in untreated and treated plots in Champaign County, Illinois

	Number of days following bait application			
Plot	**1**	**2**	**7**	**14**
Western corn rootworms				
Untreated	18.0 (3.2)*	14.0 (1.3)	13.9 (2.8)	21.2 (7.1)
Treated	2.2 (0.6)	3.6 (1.0)	2.6 (0.4)	5.4 (1.4)
Northern corn rootworms				
Untreated	3.8 (0.5)	6.9 (0.8)	8.4 (1.5)	12.4 (5.1)
Treated	0.1 (0.1)	0.3 (0.1)	0.6 (0.2)	1.4 (0.6)

Note: Traps were exposed for 24 hours.

* *SEMs* are in parentheses.

Chapter 5

Illinois, Tazewell County

Eli Levine and Hassan Oloumi-Sadeghi

Materials and Methods

A 16-ha field located near Morton, in Tazewell County, was treated with the semiochemical bait. The field had been planted in maize for several consecutive years. The application was made before 9:00 a.m., and the plant canopy was covered with heavy dew. A 32-ha field located 1 km away that had been planted in maize for several years and was farmed by the same grower was not treated and served as a control. In the treated field, maize ('Pioneer 3585') was planted in 96.5-cm rows at a plant population of 70,400 seeds/ha on April 25, 1990, DOY 115. 'Pioneer 3379' was planted in 96.5-cm rows at a plant population of 69,200 seeds/ha on DOY 116, April 26, in the control field. When the bait was applied on DOY 222, August 10, dissections of female beetles indicated some were sexually mature and that egg laying was beginning.

Beetle populations were monitored every 4–8 days from DOY 218 (pretreatment) to DOY 244, (August 6–September 1), by counting the number of adults of northern and western corn rootworms on 54 randomly selected plants in each field.

On DOY 299, October 26, immediately after harvest and fall tillage operations, soil samples were taken from both fields to determine the rate of egg laying. Samples taken at each of 10 locations consisted of two 10-cm-deep × 10-cm-diameter cores of soil spaced 4.5 m apart near the center of each field. The 2 cores from each sampling site were combined and screened through 0.64-cm hardware cloth. Then, 0.5 L of soil was processed using the methodology described by Shaw et al. (1976) to determine corn rootworm egg density per volume of soil. All eggs were identified according to species, based on chorionic sculpturing with a compound microscope (Atyeo et al. 1964).

In 1991, maize ('Pioneer 3417') was planted in 96.5-cm rows at a plant density of 69,200 seeds/ha. The planting took place on DOY 112, April 22, in the field that was treated with bait in 1990 and on DOY 113, April 23, in the untreated field. In both fields, fonofos (1.1 kg AI/ha) was applied at planting in a 18-cm band over the row. 'Pioneer 3417' was also hand-planted midway between the treated rows in several portions of each field on DOY 129, May 9; these latter plantings were not treated with insecticide. On DOY 191, July 10, 40 roots treated with fonofos (10 roots from each of 4 areas of the field) and 20 roots not treated with insecticide were dug from each field, washed, and rated for corn rootworm larval feeding damage (Hills and Peters 1971) to evaluate the effectiveness of the bait in reducing egg laying and subsequent root damage.

Results and Discussion

Before application of the semiochemical-based bait, the corn rootworm population in the treated field comprised 32 percent western corn rootworms and 68 percent northern corn rootworms. The number of beetles per plant decreased drastically after bait application and remained below the nominal economic threshold of one beetle per plant throughout the rest of the season (table 1). In contrast, beetle densities in the untreated field remained above the economic threshold through DOY 237, August 25. Significant differences between plant counts for the treated and untreated fields persisted through the last sampling date (table 1). The bait was equally effective on northern and western corn rootworms and did not appear to have any detrimental effect on beneficial insects. Success in population suppression over an extended period was probably due in large part to the lack of significant rainfall from bait application on DOY 222 through DOY 231 (August 10–19).

More western and northern corn rootworm eggs were laid in the untreated field (4.9 eggs/0.5 L soil) than in the treated field (3.1 eggs/0.5 L soil). Although the difference was not significant at the 5-percent level ($\alpha = 0.17$, *t*-test), it may in actuality be real, owing to the tremendous variability in egg distribution within plots and the relatively small number of samples taken from each field.

There were significant differences in root ratings between treated and untreated fields based on Hills and Peters' 6-point rating scale (1971), where 1 = little or no damage and 6 = 3 or more nodes of roots destroyed. For the roots in plots treated at planting with fonofos, damage ratings averaged 3.8 and 4.2 in bait-treated and untreated fields, respectively ($\alpha = 0.06$, *t*-test). Average root ratings from plots not treated with a soil insecticide at planting were 4.3 and 4.7 for the bait-treated and untreated fields, respectively ($\alpha = 0.07$, *t*-test). Lack of greater differences in root ratings between the field treated with bait and the untreated field is perplexing, especially considering the dramatic reduction in beetle populations that occurred in the treated fields. Possible explanations may include the following: (1) some rootworm eggs may have been laid before bait application (that is, we may not have applied the bait soon enough), and (2) egg-laying females may not have been detected in our plant

counts; they may have been at ground level or they may have come in at night.

Conclusions

Granular bait application effectively reduced the number of northern and western corn rootworm beetles in treated plots. Granules were equally effective against both rootworm species. Management was achieved over 2–3 wk due to lack of significant rainfall, which would have washed away the bait. The population suppression appeared to provide some root protection from larval feeding during the following growing season.

Table 1. Average number of western and northern corn rootworm beetles per plant following application of semiochemical-based bait on treated and untreated fields in Tazwell County, Illinois

	Western corn rootworms		Northern corn rootworms	
Day of year	Untreated*	Treated*	Untreated	Treated
218	0.74 a†	0.46 a	1.31 a	1.24 a
222	bait application			
225	1.15 a	0.20 b	1.11 a	0.19 b
229	0.72 a	0.02 b	0.93 a	0.15 b
237	0.35 a	0.04 b	0.19 a	0.04 b
244	0.20 a	0.02 b	0.02 a	0.02 a

* 54 plants were examined in each field.

† For each species, means within a row followed by the same letter are not significantlydifferent ($\alpha = 0.05$, *t*-test).

Chapter 6

South Dakota

D.R. Lance and G.R. Sutter

Materials and Methods

The bait was applied before 10:00 a.m. on August 11 (DOY 223) to all rows of maize in three 20- to 50-ha fields and to alternate 15-m-wide strips in a fourth 50-ha field. Little or no dew was present on the plant canopy at that time. The application rate was 10 kg/ha (30 g/ha of carbaryl) for the first three sites and half that rate in the field treated in alternate strips. At each site, a field near or adjacent to the treated field and managed by the same grower was designated as an untreated or control plot.

Site A, a 25-ha treated field, was L-shaped, with the longer arm about 750 m in length. Its paired 30-ha untreated field was located within 0.5 km and was rectangular. Site B, a treated 20-ha field, was roughly square. Its control field was approximately the same size and located about 200 m from the treated area. Unlike sites A and B, sites C and D were irrigated by center-pivot systems, each 800 × 800 m in size, with maize planted in the roughly circular, irrigated portion (about 50 ha of maize per field). At site C, the treated and untreated fields were adjacent and within the same section. At site D—the field treated in alternate strips—the control field was across a highway but in an adjacent quarter section.

Numbers of corn rootworm beetles were estimated using traps that caught all beetles emerging from a 91 × 61 cm area of soil (Fisher 1984). Changes in populations of live corn rootworm beetles were estimated by counting the beetles on whole maize plants (Tollefson 1986). Beetle populations were also monitored with unbaited yellow sticky traps (Pherocon AM™ No-Bait) that were wrapped around maize plants at ear height. The numbers of dead and dying beetles falling to the ground were estimated by counting the beetles on 96 × 104 cm framed screens laid between rows just before bait application.

At sites A, B, and C, 12 yellow sticky traps were placed in each field in 2 rows of 6 traps each. The 6 traps within each row were divided into 2 groups of 3; 50 m separated traps within groups, and groups of traps were at least 150 m apart and at least 50 m from the edges of fields. An emergence trap and a framed screen were placed within 5 m of each sticky trap. To estimate the number of eggs per liter of soil in each field at the end of the growing season, 3 soil cores (10 cm diameter × 10 cm deep) were taken with a golf-cup cutter from each of 2 locations in the vicinity of each trap (24 locations per field). The 3 cores from each location were pooled, and eggs were washed from a 1-L sample of soil taken from the pooled cores, using the methods described by Shaw et al. (1976). All eggs were identified for species, using a phase-contrast microscope.

At Site D, 6 sticky traps were placed in each field in 2 rows of 3 traps each. Each row was divided into three 180-m blocks, and 1 trap was assigned randomly to 1 of 6 positions, 30 m apart, within each block. Each block also contained 2 emergence traps. The framed screens were not used at Site D.

All plots were monitored on a regular basis—twice weekly when possible—from DOY 204 to DOY 256 (July 23 to September 13). During each monitoring period, all live rootworm beetles were counted on 54 maize plants at each of sites A–C and 20 plants at site D throughout each plot (Tollefson 1986), and rootworm beetles in emergence traps, sticky traps, and screen trays were removed and taken to the laboratory for determination of species and sex. Sticky traps were replaced every 1 to 2 weeks to maintain their efficiency. All sticky traps were removed just before bait application and replaced with new traps after application.

Results and Discussion

We believe that population densities of beetles in our plots were well suited for evaluating adult corn rootworm suppression technology. In the treated plots, the numbers of beetles emerging from the soil throughout the season ranged from about 11 beetles/m of row at site A up to about 40/m at site C (figs. 1–3). Before the bait was applied, populations of corn rootworm beetles in the treated fields appeared to be somewhat higher than those in the untreated fields, although the untreated fields contained sufficient numbers to allow reasonable comparisons (figs. 4–10). At the time of bait application, the average number of northern and western corn rootworm beetles in treated fields totaled 5 per plant at site D, 1.7 per plant at site B, and almost 3 per plant at sites A and C (figs. 4–7). All fields had beetle populations above the economic threshold of one beetle per plant, but these levels were low enough that an effective suppression technology should have been able to reduce the numbers to well below the threshold. At sites A–C, emergence data, trap catch, and counts of beetles on plants indicated that northern corn rootworms were more numerous than western corn rootworms, except in the untreated field at site A, where numbers of the two were compa-

rable. At site D, western corn rootworms were the predominate species (data not shown).

Weather during the test was near normal for that time of the year in South Dakota. Daily temperatures ranged from 12–30 °C for the 4-wk period after application. Two consecutive days of rainfall over 1.5 cm occurred on DOYs 231 and 232.

When compared with the beetles counted directly before bait was applied, the numbers of beetles on plants decreased 26–69 percent following bait application in sites A–C (figs. 5–7). These percentages may underestimate the actual effect of the bait, because counts of beetles increased in the untreated fields during this period. Relative to the numbers of beetles in untreated fields (see Lance and Sutter 1992), numbers of beetles on plants in treated fields were reduced 68–82 percent following the application. The reason beetles increased in untreated fields during this period is unknown, because emergence was almost complete at the time of application (figs. 1–3). With the exception of western corn rootworms at site B, counts of beetles on plants in the treated areas declined following application of the bait at sites A–C (fig. 5–7). Despite this, posttreatment changes in counts of beetles at sites B and C were of a magnitude that could have been expected simply from normal variation in sampling or seasonal trends in populations. At site D, many dead beetles were observed on the soil surface after bait application, but counts of beetles on plants were actually higher following application than before it. Based on plant counts, the bait had no apparent effect on overall population trends at site D (fig. 4).

The numbers of beetles captured on sticky traps generally followed the same trends as counts of beetles on plants (figs. 4, 8–10). Trap catches in the early and midseason were heavily biased toward males, so the effects of baits on females could not be ascertained from sticky trap data. Except for northern corn rootworms at site A, the bait appeared to have a greater effect in reducing trap catch than beetle densities per plant. We do not know if this effect is simply the result of sampling error or if it indicates the bait influences the activity of the beetles and, thus, their likelihood of being captured or counted.

Even though the bait killed large numbers of beetles at the time of application, it appeared to have little residual activity. Since the plant canopy was nearly dry at application, many of the granules fell to the ground; few could be found on plants several days after application. At the sites where trays were used, 2–16 beetles/m of row were recorded 2 days after application; few were found in subsequent days (fig. 11). No dead beetles were found in screen trays in untreated fields, so all mortality shown in treated fields can be attributed to the bait.

Part of the decrease in dead beetles after DOY 225 was simply due to the reduction in live beetles in the fields, but a large part was due to a decline in the effectiveness of the bait. Very few beetles were killed from about DOY 228 to DOY 233 (fig. 11), although substantial numbers of live beetles (especially northern corn rootworms) were present on the plants during the period (figs. 5–10). Accordingly, populations of beetles in the treated fields remained fairly stable immediately following the initial knockdown from the bait. Moreover, the numbers typically remained near or above the accepted threshold of one beetle per plant through the remainder of the season (figs. 5–7).

The bait had little apparent effect on numbers of eggs in the fields at the end of the season (fig. 12). Numbers of northern corn rootworm eggs did not vary significantly between treated and untreated fields ($\alpha = 0.05$; Mann-Whitney U-test). At sites A and C, more northern corn rootworm eggs were recovered from treated fields than untreated fields. The bait was more consistent in producing reductions in numbers of western corn rootworm eggs (fig. 12), although the difference was significant only at site C.

Overall, data from emergence traps, sticky traps, and dead beetle counts were fairly consistent from one field to the next. For example, numbers of beetles in emergence traps and on sticky traps were about four times higher at site C than site A (figs. 1, 3, 8, 10). Numbers of dead beetles was 7 to 8 times higher at site C than site A (fig. 11), but based on trap catch, the bait appeared to be more effective, at least against *D. barberi,* at site C than at site A. Values for site B were intermediate to those for the other two sites (figs. 2, 6, 9). Counts of beetles on plants were not consistent with the other three parameters. These counts indicated (1) the bait had the greatest effect at site A and (2) less than a two-fold difference in numbers of beetles in treated fields just before the bait was applied.

Conclusions

The bait killed large numbers of beetles but did not reduce populations sufficiently for management purposes. As in smaller scale field trials (Lance and Sutter 1992), the biocidal activity of the bait appeared to be limited because it did not remain on leaves and in leaf axils. Corn rootworm beetles spend most of their time on the aerial portions of maize plants and are unlikely to encounter bait particles on the soil surface (Lance and Sutter 1991, Weissling and Meinke 1991b).

Although we did not measure how much of the bait fell to the ground at application, we would estimate that only 20–30 percent lodged on the plant. Of the bait that initially lodged on plants, most apparently blew off, although mean daily wind speeds at 1 m above the canopy were less than 2 m/sec for the week following application. No measurable rain fell during the week after application, and irrigation was turned off for the week at site C. The irrigation system was used at site D, but no record was made of the total amount of water applied. Regardless, within a few days after application, the bait particles were not readily apparent on plants. This positional effect likely contributed to the poor initial knockdown and to the short residual activity of the bait. These data suggest that development of a stable, edible carrier which is highly palatable to corn rootworm beetles and which sticks to the plant is perhaps of highest priority in the development of semiochemical-based corn rootworm management programs.

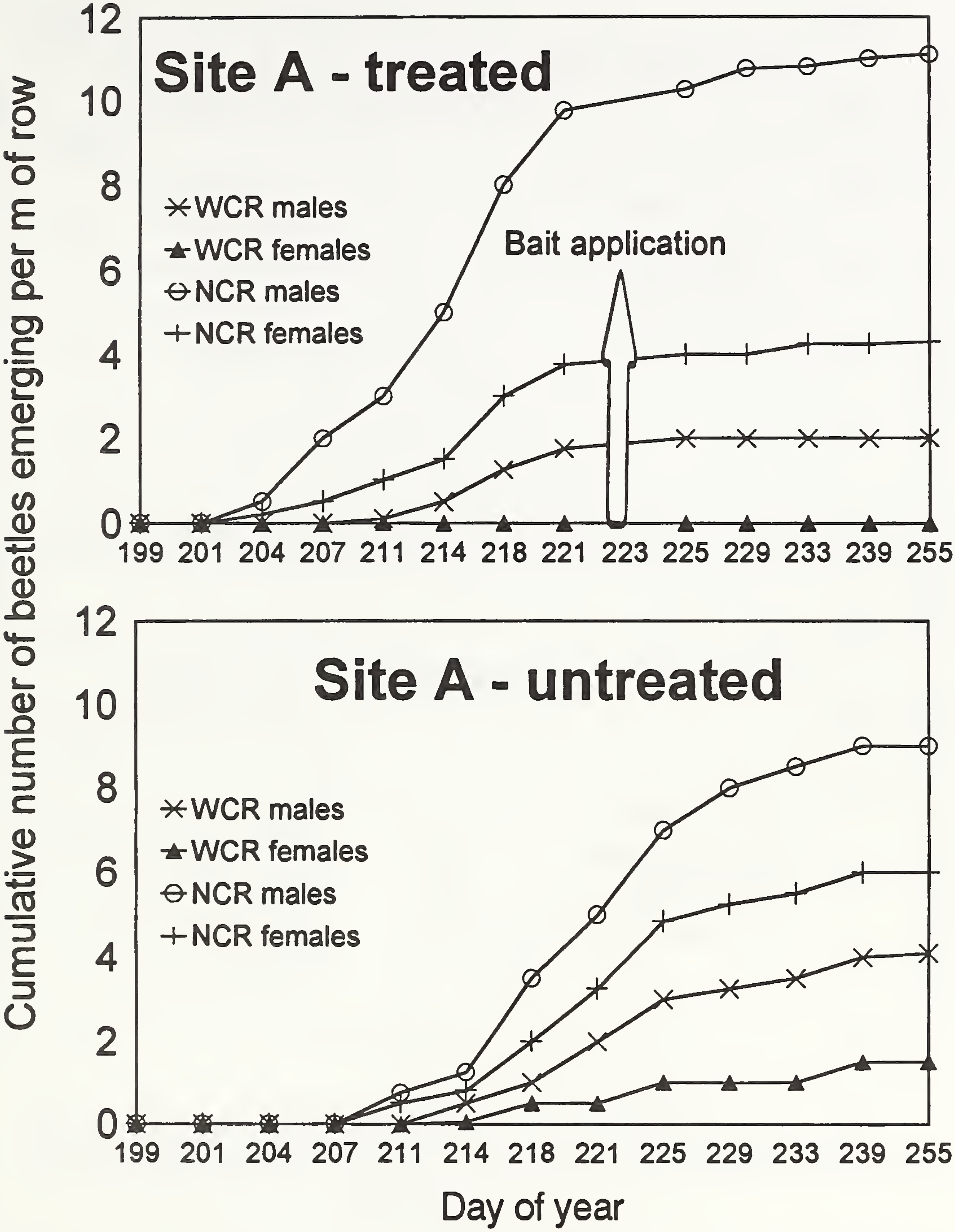

Figure 1. Cumulative northern and western corn rootworm beetle emergence per meter of row in maize fields at site A in eastern South Dakota. Number of traps = 12. WRC = western corn rootworms, NCR = northern corn rootworms.

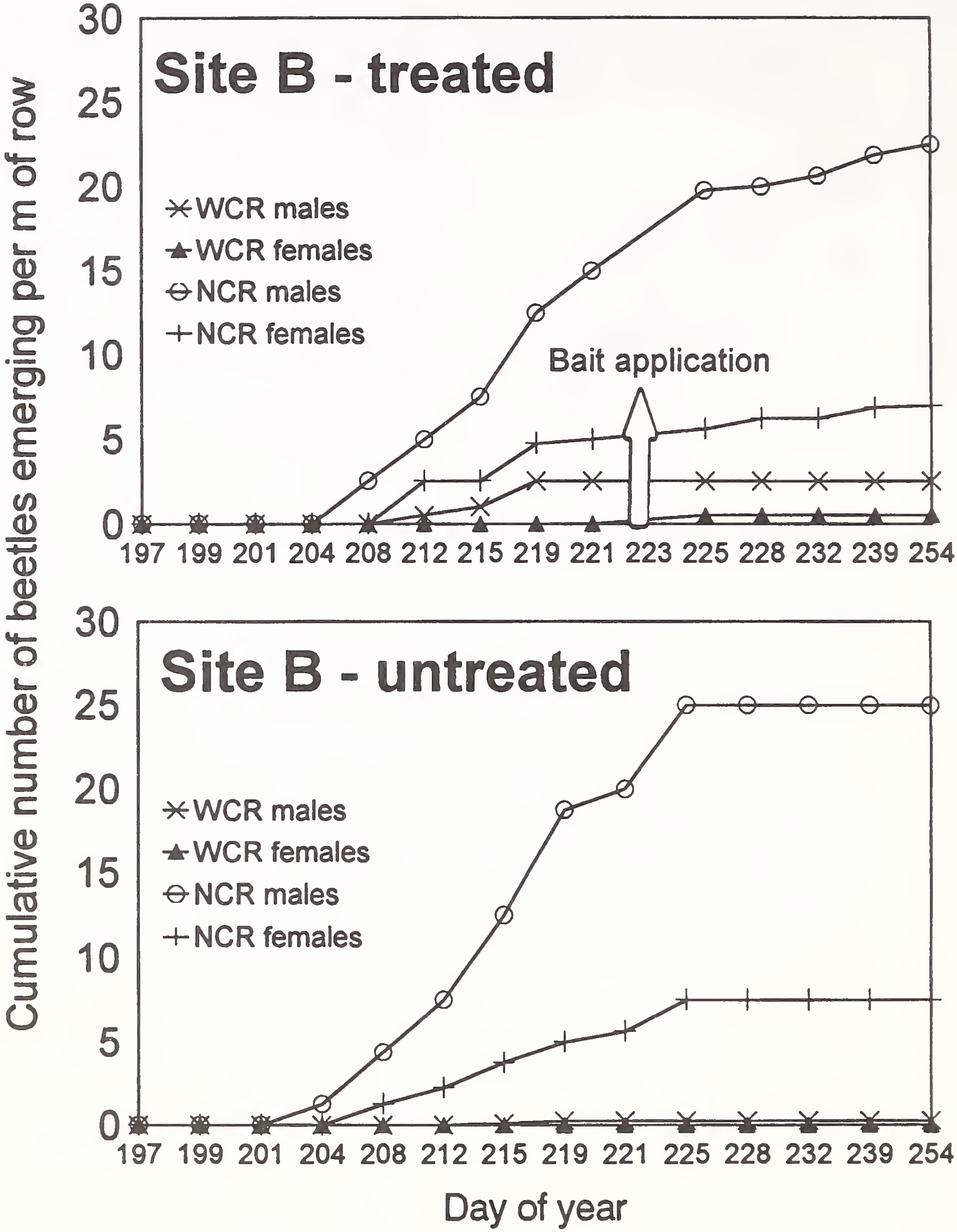

Figure 2. Cumulative northern and western corn rootworm beetle emergence per meter of row in maize fields at site B in eastern South Dakota. Number of traps = 12. WRC = western corn rootworms, NCR = northern corn rootworms.

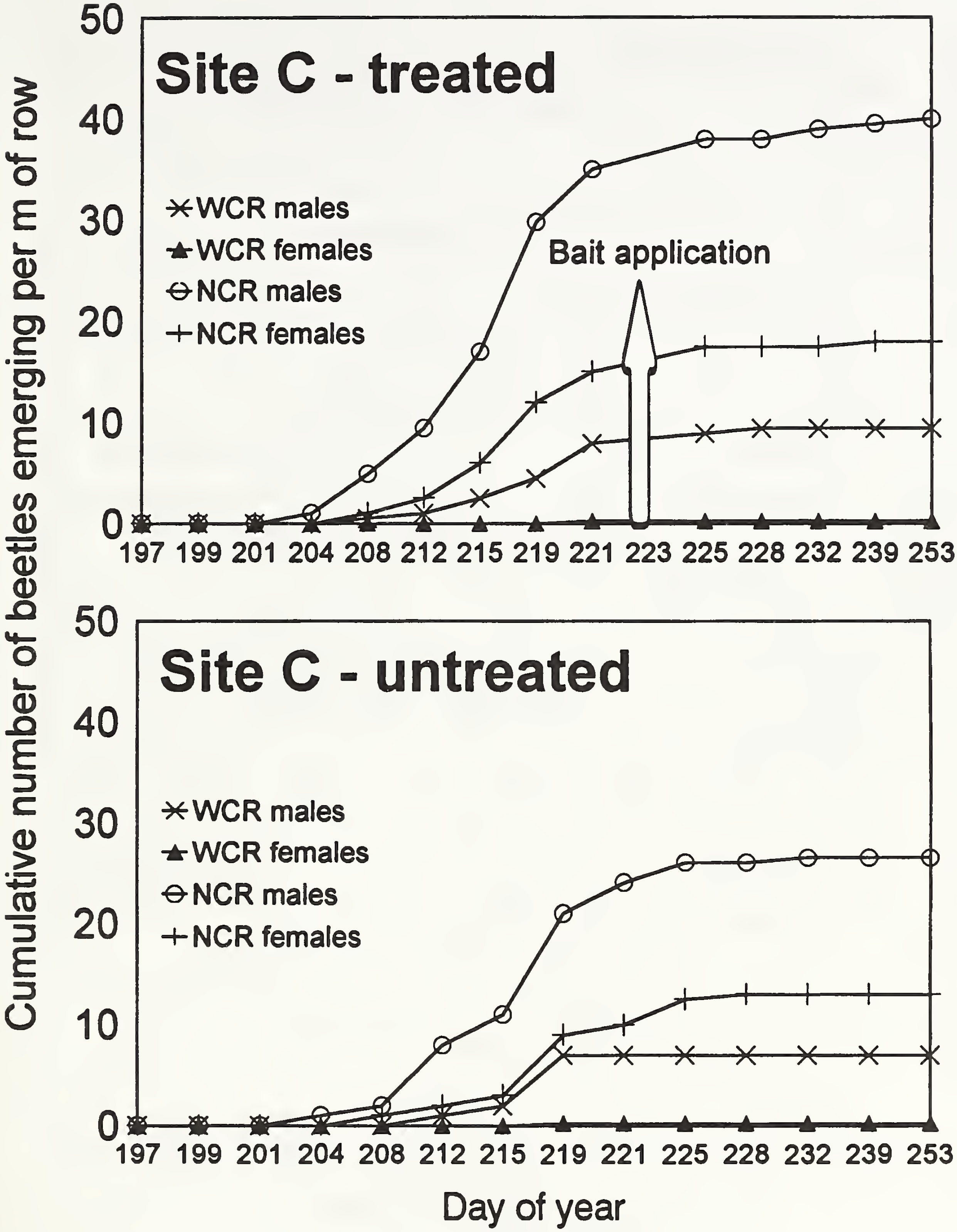

Figure 3. Cumulative northern and western corn rootworm beetle emergence per meter of row in maize fields at site C in eastern South Dakota. Number of traps = 12. WRC = western corn rootworms, NCR = northern corn rootworms.

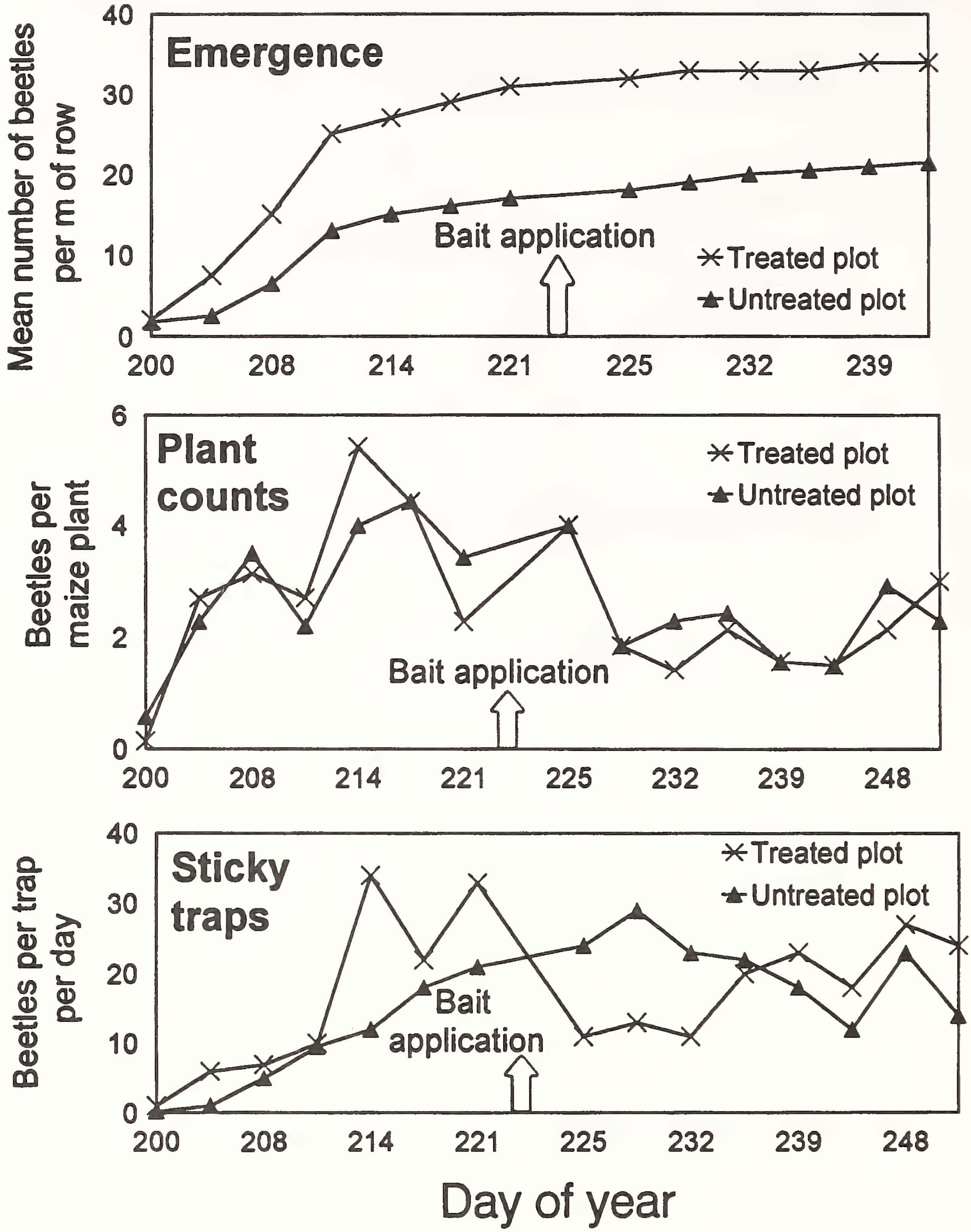

Figure 4. Numbers of northern and western corn rootworm beetles sampled in plots that were treated in alternate 15-m-wide strips or that were untreated

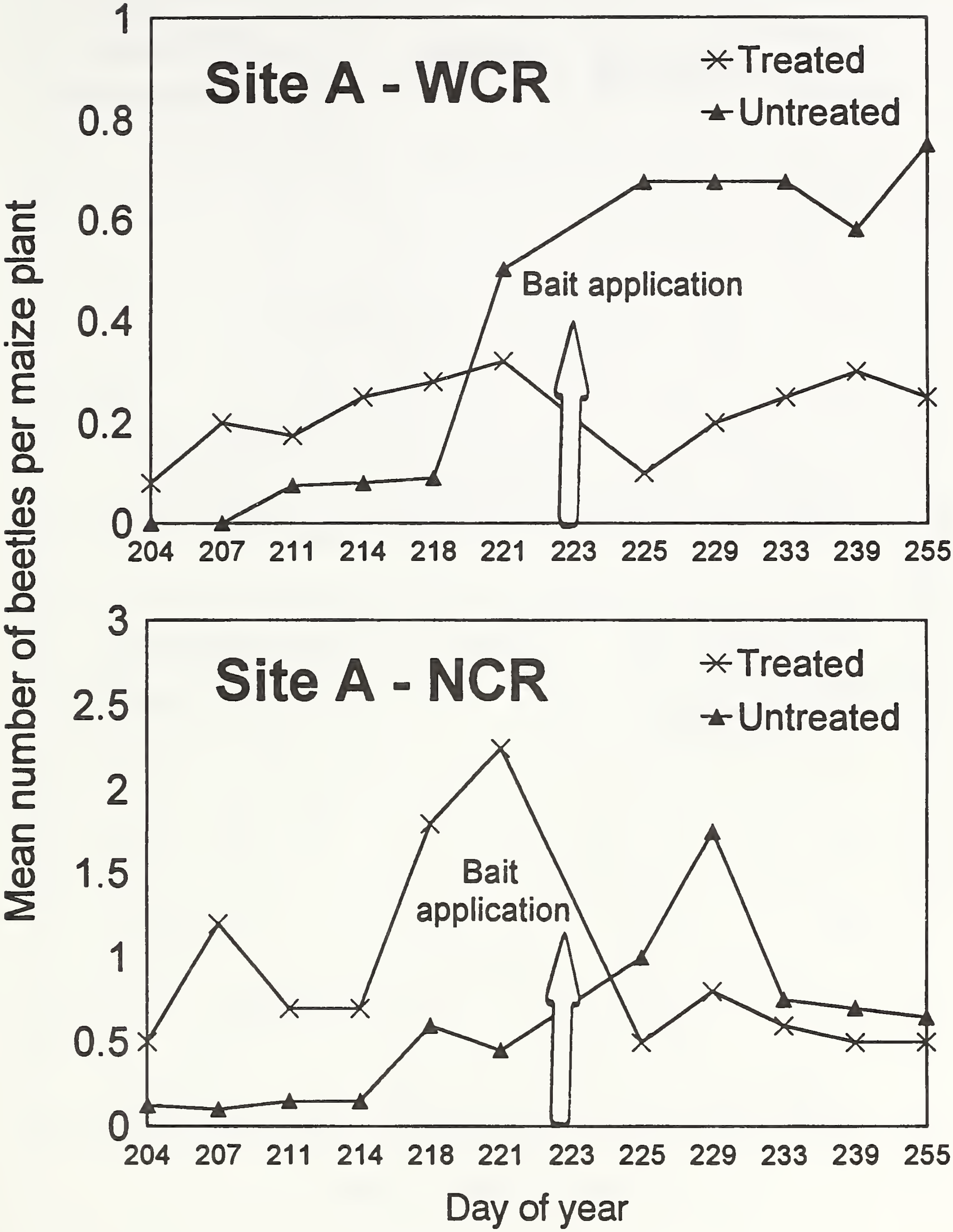

Figure 5. Numbers of western and northern corn rootworm beetles counted on whole maize plants (N = 54) at site A in eastern South Dakota. WRC = western corn rootworms, NCR = northern corn rootworms.

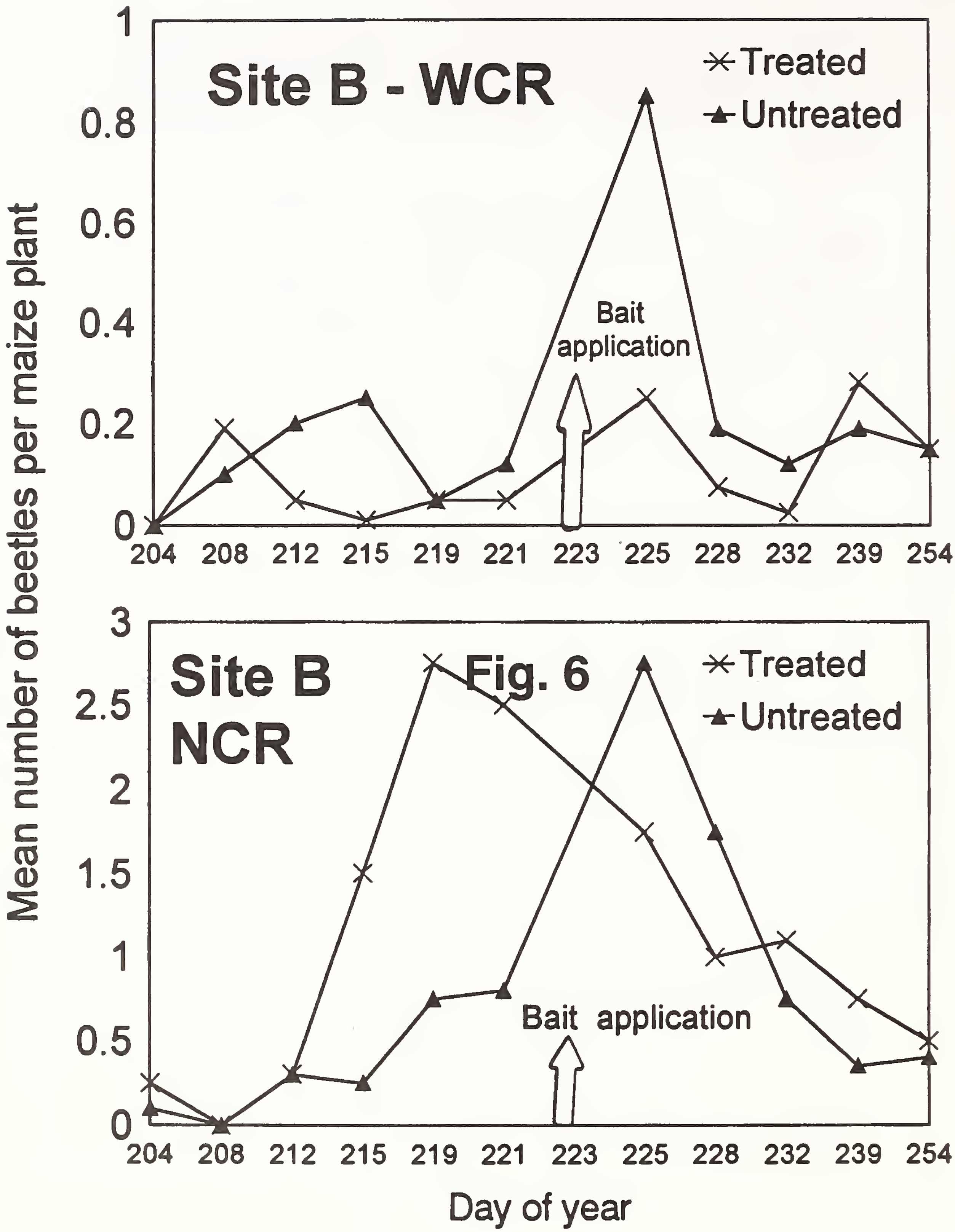

Figure 6. Numbers of western and northern corn rootworm beetles counted on whole maize plants (N = 54) at site B in eastern South Dakota. WRC = western corn rootworms, NCR = northern corn rootworms.

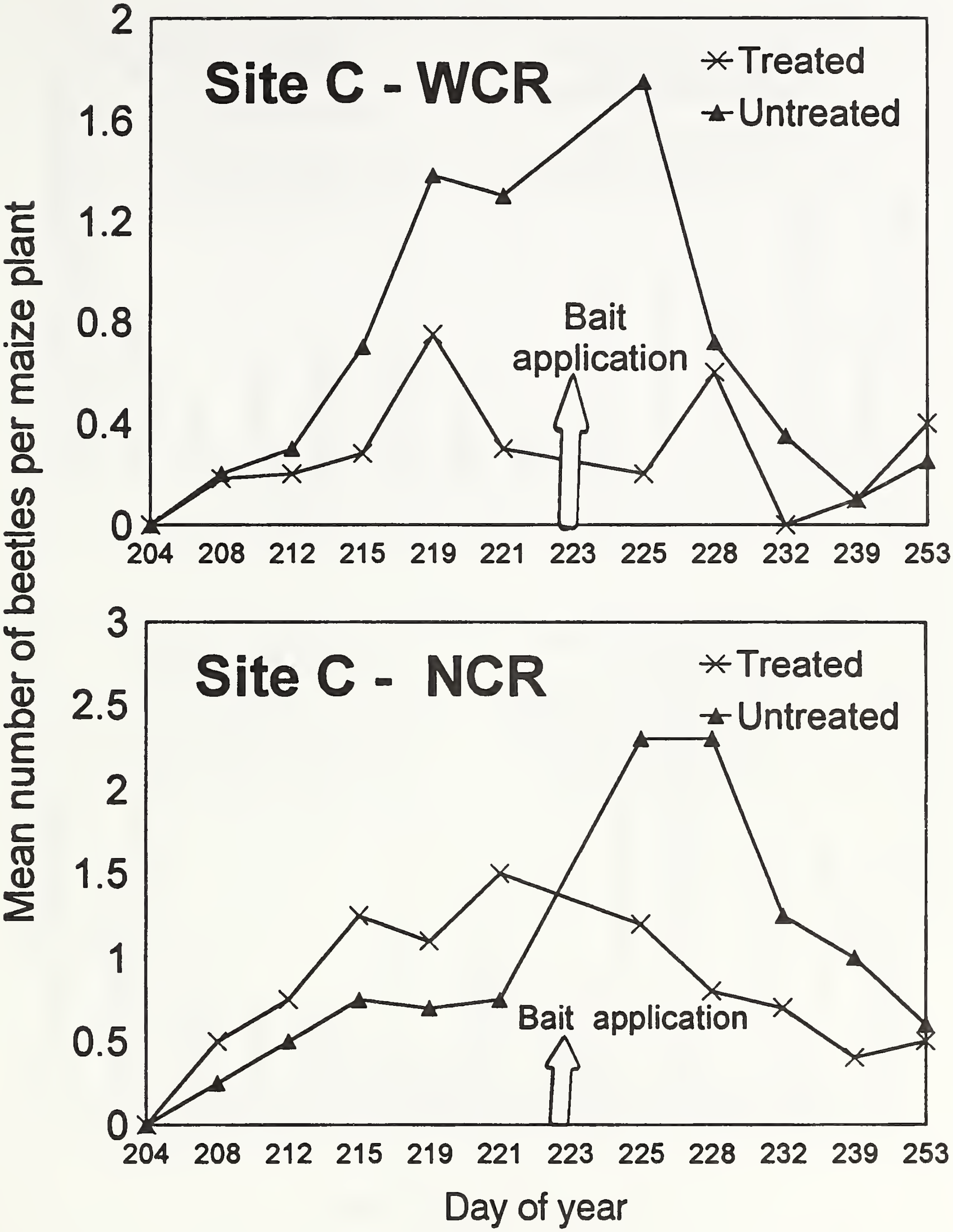

Figure 7. Numbers of western and northern corn rootworm beetles counted on whole maize plants (N = 54) at site C in eastern South Dakota. WRC = western corn rootworms, NCR = northern corn rootworms.

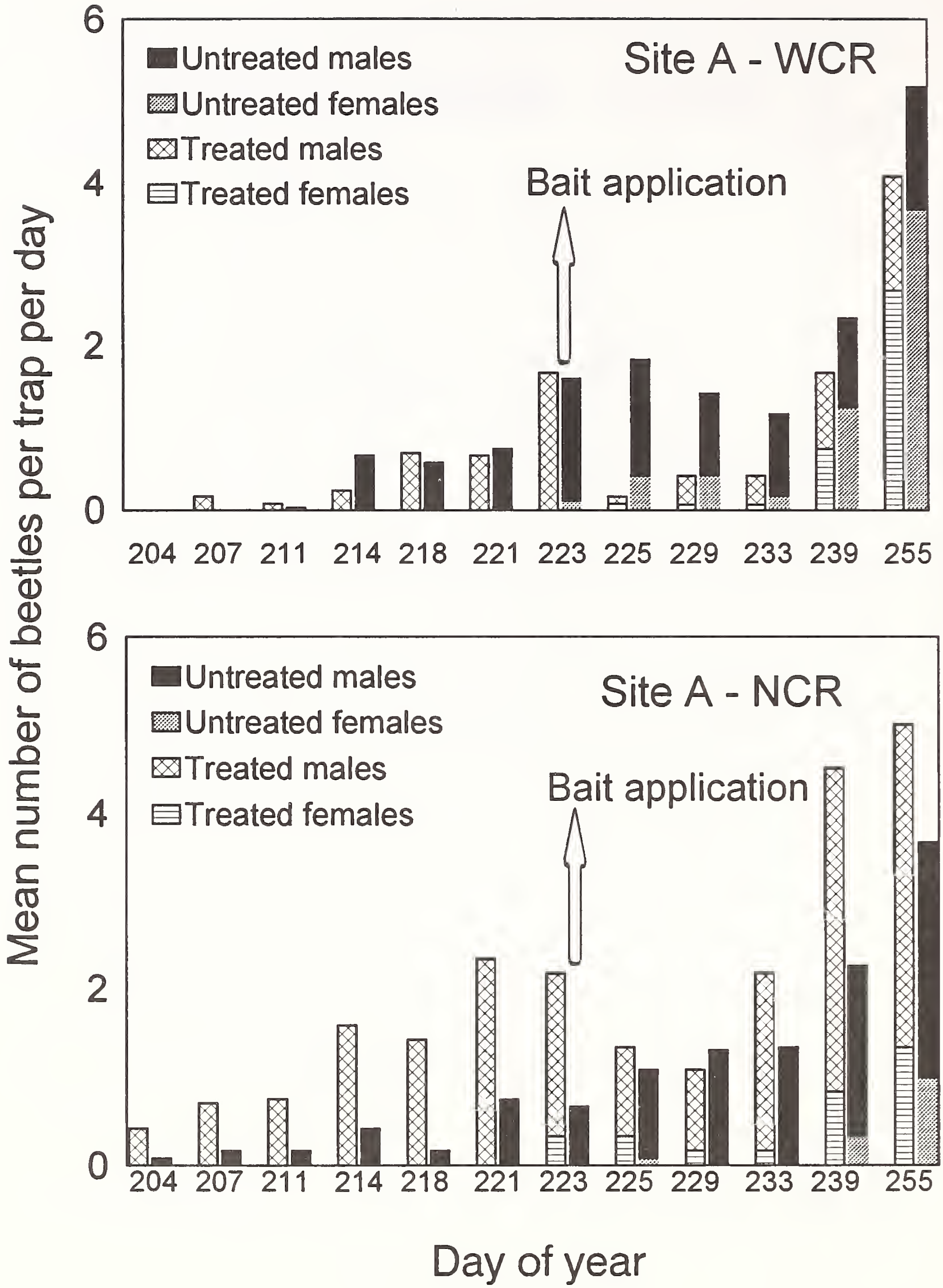

Figure 8. Numbers of western and northern corn rootworm beetles captured on unbaited yellow sticky traps (N = 12) maize fields at site A in eastern South Dakota. WRC = western corn rootworms, NCR = northern corn rootworms.

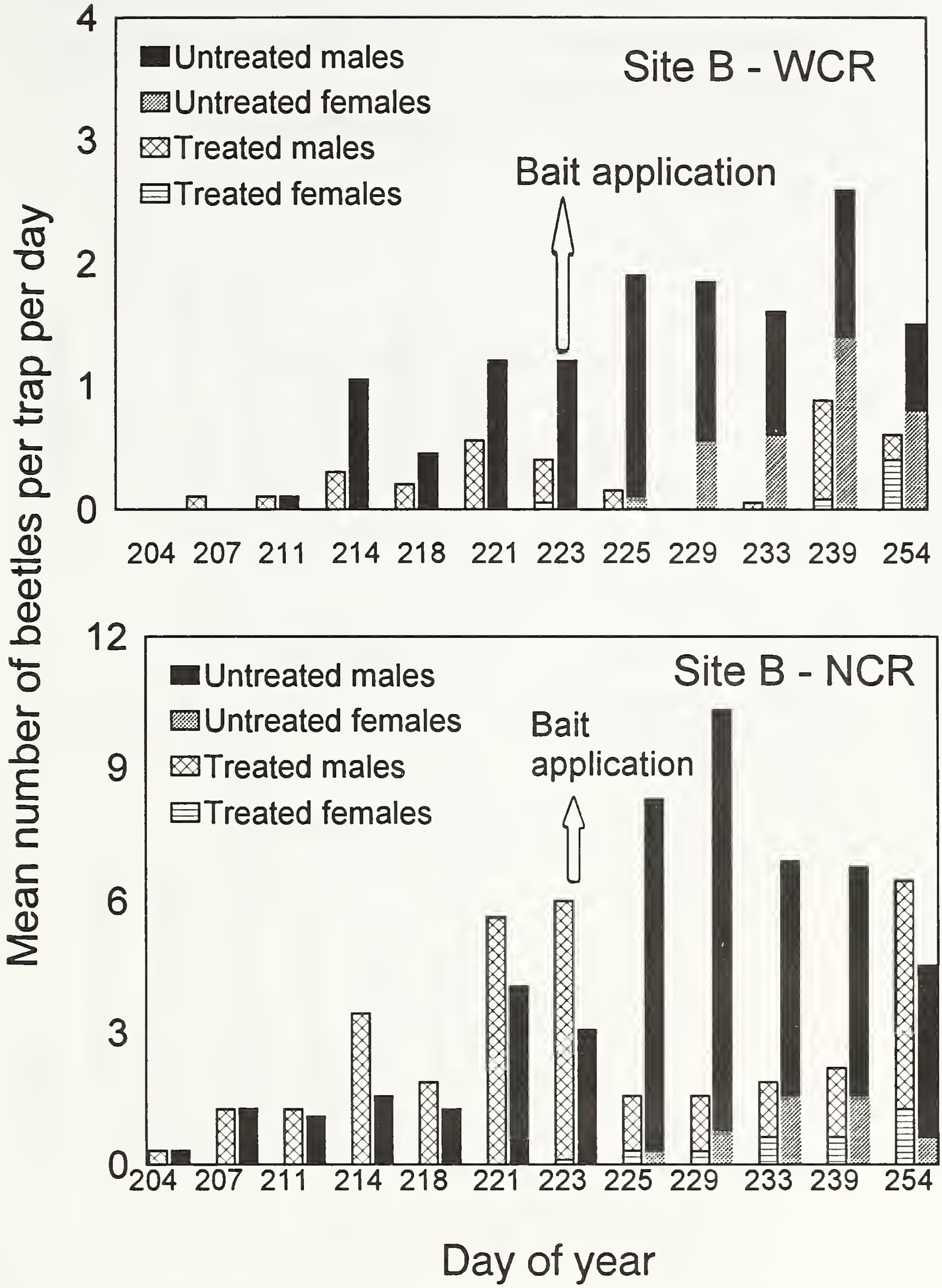

Figure 9. Numbers of western and northern corn rootworm beetles captured on unbaited yellow sticky traps (N = 12) in treated and untreated maize fields at site B in eastern South Dakota. WRC = western corn rootworms, NCR = northern corn rootworms.

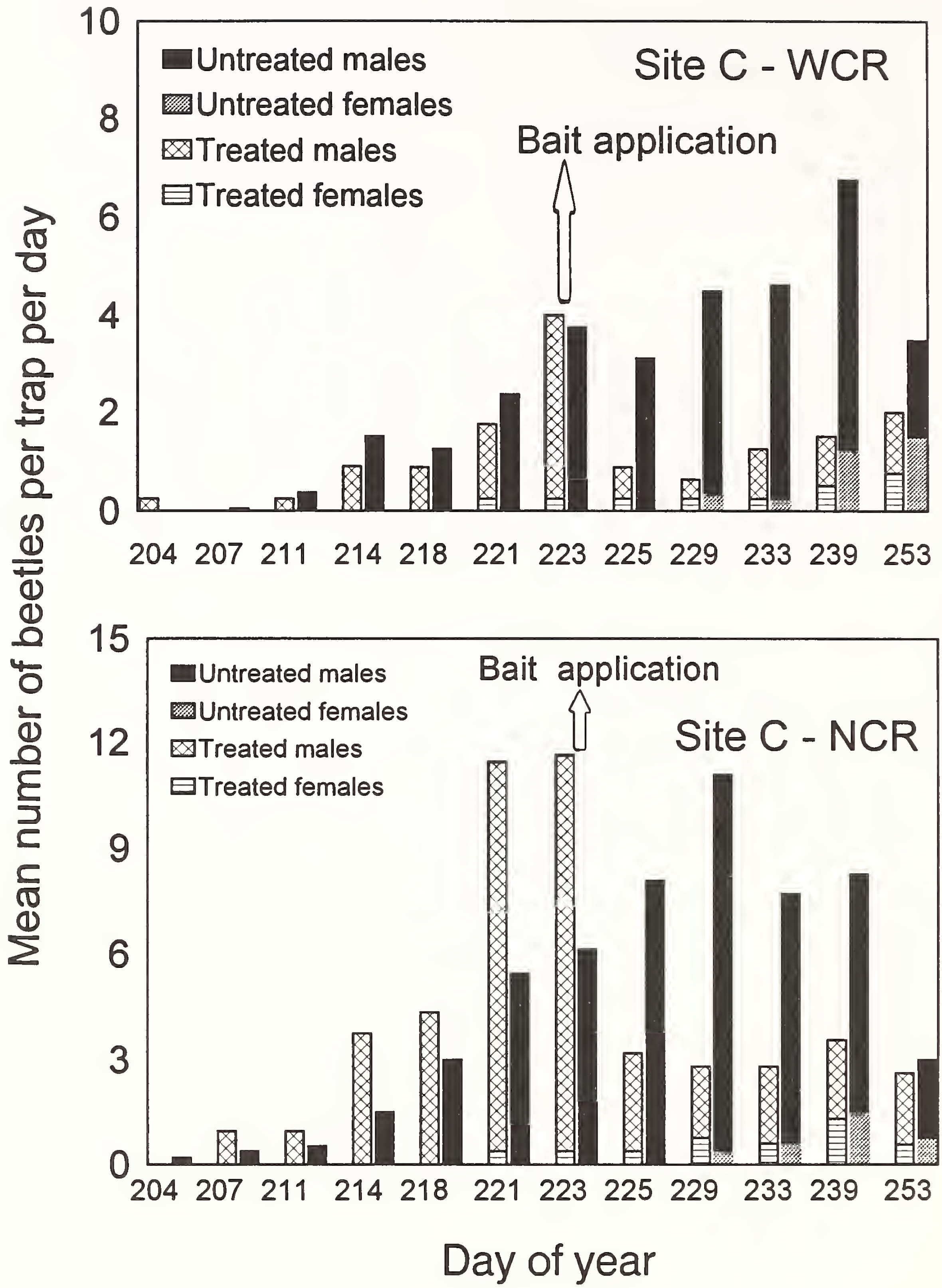

Figure 10. Numbers of western and northern corn rootworm beetles captured on unbaited yellow sticky traps (N = 12) in treated and untreated maize fields at site C in eastern South Dakota. WRC = western corn rootworms, NCR = northern corn rootworms.

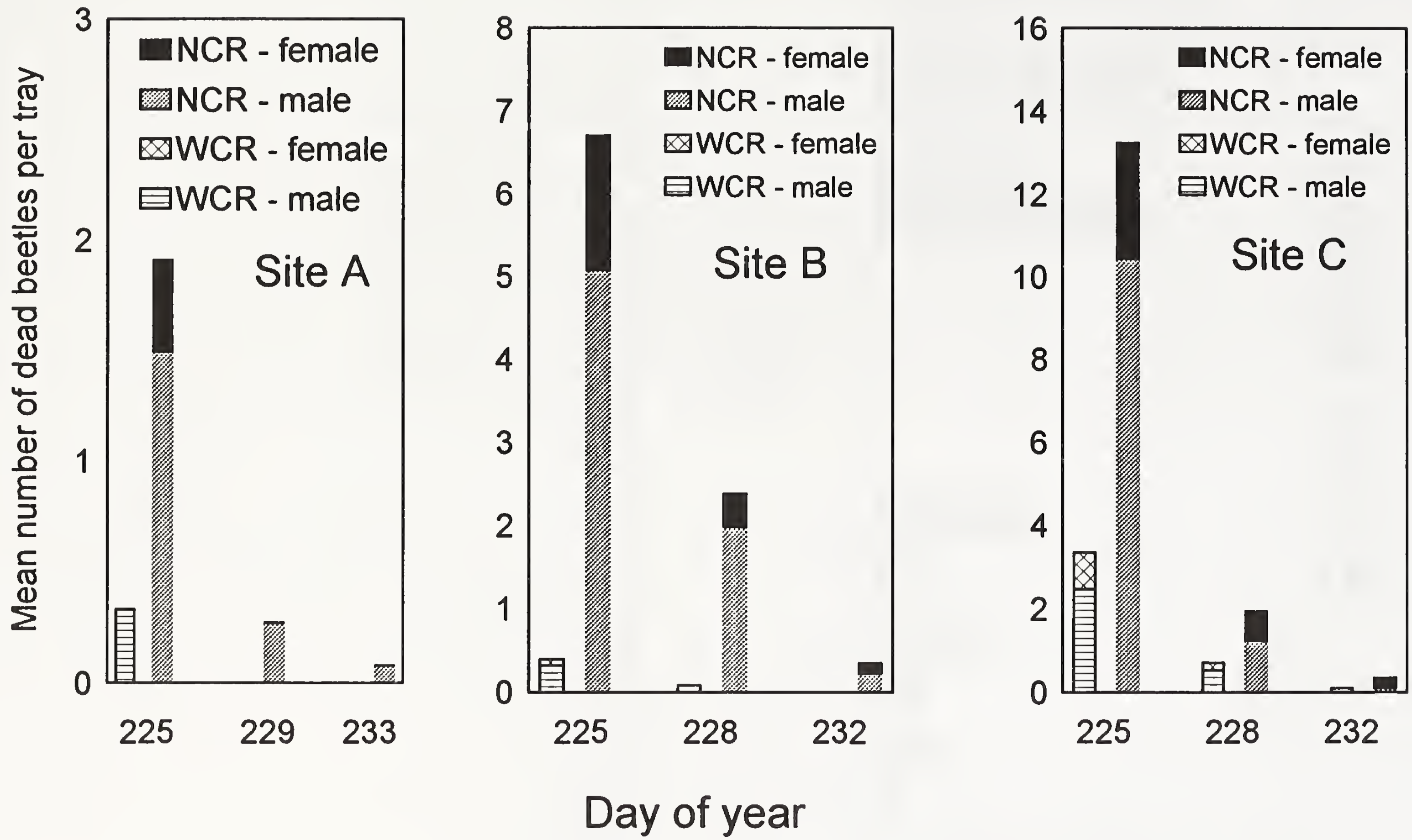

Figure 11. Mean numbers of dead western and northern corn rootworm beetles recovered from screen trays (N = 12) placed on the soil surface in treated and untreated maize fields at three sites in eastern South Dakota. No dead beetles were found in the untreated fields. WRC = western corn rootworms, NCR = northern corn rootworms.

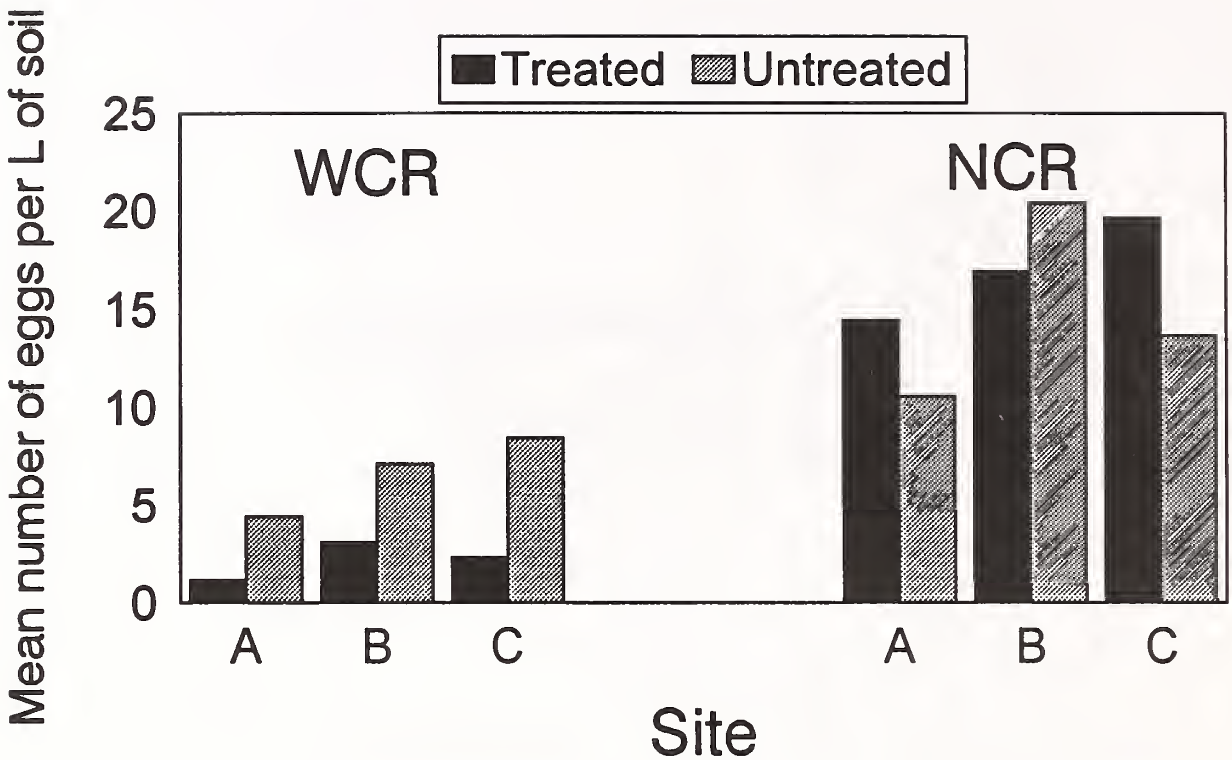

Figure 12. Mean numbers of northern and western corn rootworm eggs in soil samples (N = 24) taken from treated and untreated maize fields at three sites in eastern South Dakota. WRC = western corn rootworms, NCR = northern corn rootworms.

Chapter 7

Synopsis of the Findings

Gerald R. Sutter

Most of the basic objectives of this regional project were achieved during the pilot study. The most significant findings and conclusions are listed following:

- Corn rootworm populations can be suppressed by semiochemical-based baits, using significantly less toxin per hectare than amounts typically applied in managing these pests.

- Corn rootworm populations throughout the major maize-producing areas appear to respond to baits in a similar manner, even under different climatic conditions and diverse agronomic practices.

- The granular formulation of semiochemical-based bait has several characteristics that are not desirable for management of corn rootworms in maize production. Even though it was easy to handle and apply in the field, the formulation did not readily adhere to plant structures such as leaves and leaf axils and was easily blown or washed from the plant to the soil surface. Baits must remain on plants and be readily available to beetles to be effective. Better knockdown appeared to occur when the bait granules were applied to plants covered with dew and when rainfall did not occur soon after application.

- This granular formulation lacked sufficient physical stability, long-term biocidal activity, and palatability to corn rootworm beetles under all field conditions to effectively suppress populations throughout the egg-laying period. Most evaluations indicated the bait had minimal impact on the prevention of egg laying.

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